Fundamental Practical Physics

Dr. D.P. Ray Chaudhuri

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A Mukherjee & Co Pvt Ltd

Written according to the revised Syllabus introduced by the West Bengal Council of Higher Secondary Education for Classes XI and XII.

FUNDAMENTAL PRACTICAL PHYSICS

(FOR CLASSES XI & XII)

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PREFACE

The book is written according to the newly introduced syllabus for Classes XI and XII of the Higher Secondary Course with effect from 1985. The experiments have been grouped according to the branch of Physics to which they belong.

A list of the apparatus and accessories required for an experiment has been given at the beginning of the work. There are different forms of apparatus for the same experiments. It is not possible to describe all of them. So, We have described only those which are more common and are used more often. The teacher will kindly help the student if the apparatus to be used is different from the one described. In doing so, the sameness of the principle should be pointed out.

For every experiment, detailed instructions have been given about how to do it. The way how to *write up* the experiment has also been shown in each case. Where the 'Observations' can be recorded in a tabular form, the form of the table has been shown. In some cases, the steps in the experiment have been illustrated with diagrams. I hope these will help the student in his work, and the teacher in his supervision. But a book can never replace the teacher. The teacher is indispensable.

Before discussing the experiments of a group, some basic matter relating to the group has been explained. For example, before taking up the experiments on 'Current Electricity', we have tried to give the student a working idea of the 'electric cell', 'voltage of a cell', 'resistance boxes', 'rheostats', 'the electric circuit', 'key', etc. May be, some student will have to do some electrical experiment before he has read enough about electricity. Such material is likely to help him and reduce the teacher's load.

Two things, though not specifically mentioned in the syllabus, are essential to all experimental work. These are: (*i*) an idea of **experimental error** and (*ii*) an idea of the number of **significant digits** in a measurement. Without these ideas, laboratory work becomes senseless mechanical work. Unfortunately, such senseless work is much more common than is supposed. It may be seen even at the post-graduate level.

It should be the duty of a teacher to draw the attention of the students to these two ideas. To help him in this work we have included the basic material on 'Experimental errors' and 'Significant digits' in Sections 1-4, 5 and 6. We would request the teacher to refer the student to these sections. The student should further be advised to apply this knowledge to his work so far as he can. No one expects him to be able to apply the knowledge satisfactorily from the beginning. But he is sure to improve as he progresses.

After the student has learned about logarithms in his mathematics class, he should be encouraged to use log tables for calculation. At the same time he should be *warned* that the four digits he gets from the table of antilogs may not be significant.

It is usual to ask oral questions during a practical examination. The main purpose is to test whether the examinee is doing the work intelligently or mechanically. To give the student an idea of the kind of questions he may be so asked, a few probable questions have been added at the end of each experiment. The weaker student needs some guidance in finding the answer to such a question. This has also been provided.

A puzzling feature of the syllabus is the wide difference in the relative difficulties of the experiments. A specific gravity determination involves three or four simple weighings. The use of a P. O. box is complicated by the hidden circuity and the wide choice of resistances to be used, as well as controlling the current to get the necessary sensitivity. Using a P.O. Box properly or measuring Young's modulus is not a simple experiment when done for the first time. It is unlikely that the time table will allow the student to repeat the more difficult experiments till he acquires skill enough to handle them with confidence.

The first edition of a book is likely to contain errors and omissions, though all possible care has been taken to eliminate them. Intimation of any error or omission will be gratefully acknowledged, and so also any suggestion for improvement.

July, 1985.

D. P. R.

D. R.

THE COUNCIL OF HIGHER SECONDARY EDUCATION

(NEW SYLLABUS WITH EFFECT FROM 1985)

PHYSICS PRACTICAL

Two experiments-one from each Group—A and Group—B are to be performed in the practical examination. Idea about eye-estimation (question will not be set).

Group—A

1. (*a*) To Determine the volume of a rectangular parallelopiped or a cylinder with the help of slide callipers.

(*b*) To Determine the cross-section of a given wire by using a screw-gauge.

(*c*) To Determine the thickness of a given glass plate by using a spherometer.

2. To Determine the volume of a given solid of irregular shape, heavier than and insoluble in water by hydro-static balance.

3. To Determine the specific gravity of a given solid of irregular shape, heavier than and insoluble in water by hydro-static balance.

4. To Determine the sp. gr. of a given liquid by the Hare's Apparatus.

5. To Determine the sp. gr. of a given liquid by the sp. gr. bottle.

6. To verify the laws of reflection of light by ray tracing with pins. (At least three different rays are to be taken).

7. To show that in case of reflection on a plane mirror the object distance is equal to the image distance. (At least three different rays are to be taken and rays to be traced with pins).

8. To verify the laws of refraction of light. (At least three different rays are to be taken.)

9. To Determine the focal length of concave mirror by the method of coincidence.

10. To Determine the velocity of sound in air by resonance of air column by elimination of end correction (neglect correction due to moisture and temp.)

11. To Determine the frequency of a tuning fork by its resonance with air column, velocity of sound being supplied.

12. To locate the poles of a given bar magnet.

N.B. At least 10 experiments including expt. No. 1 are to be taught by the institutions.

Group—B

1. To Determine the sp. gr. of a body lighter than water (wax) by using hydro-static balance.

2. To Determine the sp. gr. of a granular solid insoluble in water with the help of a sp. gr. bottle.

3. To Draw L—T^2 curve by determining time periods with the help of a simple pendulum for a least five different lengths of oscillations and to calculate the value of g, the acceleration due to gravity.

4. To verify Boyle's law for a gaseous material using five different pressures—atmospheric pressure, 2 pressures below and 2 pressures above the atmospheric pressure—by showing pv as constant.

5. To verify Hooke's law by drawing load-elongation curve.

6. To Determine the sp. heat of a given solid by the method of mixture (Radiation loss is to be neglected).

7. To Determine the focal length of a given convex lens by u—v method using pins or screen and a luminous object (At least five diff. object distances should be used.)

8. To trace magnetic lines of force due to a bar magnet when its North pole is pointing north. To obtain the positions of the neutral points also.

9. To verify ohm's law using ammeter and voltmeter.

10. To verify the laws of combination of two resistances (*a*) in series and (*b*) in parallel by using a P.O. Box.

11. To Determine the value of an unknown resistance with the help of a metre bridge (Neglect end-correction.)

12. To Determine the value of the reduction factor of a single coil tangent galvano-meter by using a known current (measured by an ammeter) and hence to determine the value of a current corresponding to a given deflection of the galvanometer.

N. B. At least 10 experiments under Group-B are to be taught by the Institutions.

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CHAPTER

1

DISCUSSION OF SOME BASIC TOPICS ON LABORATORY WORK

The beginner comes across quite a number of difficulties when he first enters the laboratory for work. This is due to his lack of knowledge about some basic facts relating to laboratory work. Unfortunately, he hardly acquires the necessary knowledge or receives the necessary instructions before beginning his work. No book can replace the teacher in giving the student the necessary knowledge or instruction. But we can at least discuss some useful things—the A B C.s of laboratory work. These may include

(1) Preparation for the experiment;
(2) Performing the experiment;
(3) Writing up the experiment (Rough and Fair Note Books);
(4) An idea of 'Significant digits' in his measurements;
(5) An idea of 'Experimental errors' in physical measurements;
(6) Drawing of graphs.

Let us deal with these one after another.

1-1. Preparation for the experiment : Before coming to the laboratory to perform an experiment, read your book and learn all that you need know to perform the experiment intelligently. If there are things you cannot understand, ask your teacher. If you have somebody in your home who can help you in such matters, take his help. Bring with you a sharpened pencil, a pen, an eraser, a transparent plastic scale, a rough note book, and preferably a geometrical instrument box.

1-2. Performing the experiment : Try to do it with intelligence and skill. The book contains the necessary instructions. If you think you can do a part of it in a better way discuss it first with your teacher. When two or more of you work together on the same experiment, none of you should be a sight-seer. Each one of you should take part in the experiment. When a reading is taken, write it down at once in your 'rough note book' under an appropriate heading. If any apparatus is broken during the work, report it immediately to the teacher-in-charge. When the work is over, dismantle the apparatus, and leave things as you found them before you began work.

1-3. Writing up the experiment : A 'write-up' of the experiment is considered an essential part of the work. There is no standard form for the 'write-up'. But there is a general agreement of opinion about what it should be like. A generally accepted pattern is shown below and has been used in this book. You may show this pattern to your teacher and ask him if he wants any change.

(i) **Heading :** Write the heading of the experiment in clear, bold letters at the top. Put the date or dates of the experiment on the left margin.

(ii) **Theory :** Write under this heading the theory to be applied to the experiment. No deduction of any formula is necessary. But you should write the formula which connects the readings to be taken with the quantity to be measured. The meanings of the symbols used in the formula should be stated.

(iii) **Apparatus :** The apparatus and other requisites should be listed under this head. This will ensure that you have all the things you want before starting the experiment.

Some teachers are of the opinion that a description of the main apparatus should be included in the 'write-up'. Perhaps they want it this way to ensure that the student is well acquainted with the apparatus. In the opinion of the authors, this is unnecessary. Unless the student is familiar with the apparatus, he cannot do the work properly and intelligently. The quality of his work will be clear from his write-up. If he is asked to include a description of the apparatus in the write-up, much of his limited time during an examination will be wasted. This time could profitably have been used in taking readings. The wasted time is longer the more complicated the appratus is.

This book, however, will contain the necessary description to help the student in understanding the construction and action.

(iv) **Diagrams :** Even though a description of the apparatus may not be required, a line diagram representing the arrangement of apparatus is often useful. It is not necessary to draw such diagrams using shades to represent a three-dimensional picture. The kind of diagrams given in the book will be good enough. They are easy to draw.

It does not mean that you should draw all the diagrams you find here. The purpose of a diagram is to bring out the experimental arrangement clearly. Where this can be done without drawing a diagram, the latter is unnecessary. When a diagram has to be drawn, it is most convenient to label the parts. This reduces the writing of the description. You will find such labelled diagrams in the book.

In electrical experiments, the **circuit diagram** must be drawn. All drawings must be in pencil.

(v) **Method :** It is generally considered necessary that a short account of the 'Procedure' or 'Method' you have followed in doing the experiment, be included in your write-up. Logically, its place is at the end of the experiment. For, after you have completed your experiment and calculated the result, you can say how you have done it. So, it is best to give a short account of the 'Procedure' or 'Method' followed, at the end of the experiment.

Since it is an account of what you have done, it is usually written in the past tense, such as 'was done', 'was weighed', 'was placed', etc. You can as well write it as 'I weighed it', 'I placed it', 'I did it', etc. We have used the past tense in illustrating 'write-up' of the 'Method'. But we have deviated occasionally and used the first person 'I'.

Statement of the method should also include a short account of any *special precautions* you might have found necessary.

Introductions for the experiment : The preceding part relates to the write-up. But before beginning an experiment the student must know how to do it. So, immediately after 'Apparatus', we have given the necessary instructions (within rectangular brackets) under the heading 'Directions for the experiment'. Write-up of the 'Method' follows on the lines of these instructions. The 'Directions' are for the student to follow. The 'Method' is for his write-up. If the teacher gives him different directions the write-up of the 'Method' has to be changed accordingly.

(vi) **Observation :** In doing the experiment, readings of the the same or different instruments have to be taken at different times. These must be recorded in the *note book* in the order they have been taken. *Never use scrap paper for recording readings.* Each reading must be given a suitable heading, so that any one who sees the record can understand what the record relates to. The nature of recording has been shown in the book under 'Observations'.

Wherever possible, use tabular forms for recording data. Such forms have been given.

The readings must be recorded *in decimals*. Keep only the 'significant digits' (See Sections 1-4 and 1-5). You will find it difficult to do so properly at the beginning. But if you remember the instructions regarding significant digits and follow them, you will gradually improve. When in doubt, ask your teacher.

The *unit* in which a quantity has been measured must be stated. You will generally use the c.g.s system of units.

(vii) **Calculations and Result :** The calculations of the result from the reading you have taken (and recorded under 'Observations') are to be shown under this heading. Show the mathematical processes of addition, subtraction, multiplication, division, etc., on the left hand page of your note book whether it is 'Rough' or 'Fair'. This is better done in pencil as corrections may be necessary. Use log tables if you know how to use them. But the four digits you obtain from such tables may not all be significant. This requires separate consideration (See Section 1-6).

(viii) **Rough Note Book and Fair Note Book :** It is the practice in our country to ask the student to maintain two* note books—one called 'Rough' and the other called 'Fair'. He is asked to bring the Rough Note-Book with him to the laboratory. The book should contain the title of the experiment, the date of its performance and the theory to be followed. If it is an electrical experiment, it must carry the circuit diagram on the left-hand page. Enter the 'Observations' in this book in the way stated earlier. If you have time, calculate the result before you leave the laboratory.

The Fair Note Book must be completed according to instruction before you begin your next experiment. In it the entries will be in the order (*i*) Heading, (*ii*) Theory, (*iii*) Apparatus (with diagram and description where required), (*iv*) Observations, (*v*) Calculations, (*vi*) Result or Conclusion, (*vii*) Method followed (including special precations taken).

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*The authors are very much against the practice of maintaining two note books. The so-called 'rough' one should be the only one. If this were insisted upon, the student would be more careful and neat in his work, and come better prepared to the laboratory. The 'Fair' note book encourages irregularity in work and various other malpractices. Though most of the teachers and educational administrators know it, none has taken any initiative to bring about a change.

Beginning students need not enter into any 'discussion' of the experiment as he is not mature enough. This may be reserved for more advanced stages.

1-4. Experimental Errors and Significant Digits in an experiment: Every measurement contains some *error*. The word 'error' does not carry any sense of blame; it means some *uncertainty* in the value obtained. When you say a length is 16 cm, it means you have not noted the number of millimetres in the length, or have ignored it. If your scale had no millimetre divisions, you might guess by *eye-estimation* (Section 2-1.2) that the millimetre portion in the length was 2. In that case you would express the length as 16·2 cm. With the scale divided in millimetres, you may estimate that there is a further 0·4 of a millimetre division in the length. You then say that the length is 16·24 cm.

From the above example, you see that in each case there is some uncertainty in the last digit because the next digit is not known. You may make the measurement finer and finer; but the last digit is always uncertain to an unknown extent.

There are two significant digits, namely 1 and 6, in your first statement of length. There is some *uncertainty* or *error* in the last digit 6, because the digit in the next decimal place is not known. (This applies even if the next digit is zero.) In such a case we assume that 16 here means any value between 15·5 and 16·5—but we do not know more precisely what it is.

When you say that the length is 16·2 cm, there is some uncertainty in the last digit 2; but the magnitude of the uncertainty is not known. So we take it that the real value lies somewhere between 16·15 cm and 16·25 cm. The measure 16·2 is given up to three significant digits. If the last digit were zero (0) instead of 2, the measure still has three significant digits. Though in arithmetic 16 and 16·0 mean the same thing, it is not so in physical measurements. 16 has two significant digits, but 16·0 has three. It means that the latter measure is more precise than the former.

When you state the length as 16·24 cm there are four significant digits in your measure. But the usual uncertainty in the last digit always persists.

As you make your measurement finer and finer, you get more significant digits in the measure. This reduces the actual or 'absolute' error in the measurement, but some uncertainty in the last digit, however small, always persists.

Causes of error. There are various reasons for error in a measurement. Here we may consider only two kinds of error, namely, (*i*) Gross error and (*ii*) Systematic error.

(*i*) **Gross error :** If in reading a scale or recording a reading you make a mistake, it is called a *gross error*. Suppose a length is 32 cm; but you read it as 82 cm or 42. cm. This is a gross error. If you write 23 cm in place of 32 cm, this is also a gross error. All of us make such mistakes some time or other, particularly when we are tired.

When more than one student take the same reading, a gross error can be eliminated if each one of them take the reading independently. When working singly, take a reading thrice. When you repeat a reading *never try to remember the reading taken earlier*. This will bias you in favour of the first reading. If the first reading was wrong, the second will also be wrong.

(*ii*) **Systematic error.** An error which always gives a higher value or always a lower value than the true one is a *systematic error*. There are several reasons for it. But we shall mention only two. One of them is called **Instrumental error.** Suppose a metre scale has lost a portion from its zero end. This scale will always give too high a value of the length it reads. In a slide callipers (Section 2-2) or a screw gauge (Section 2-3) the apparent zero may not be the true zero. An ammeter or voltmeter may not read zero even when there is no current flowing. Such instruments will always read too high or too low. Errors of this kind are instrumental errors. They can always be corrected, that is, taken into account.

Besides, different persons may differ to some extent in taking the same reading, particularly if eye-estimation is used. Similarly, differences are found in judging coincidence between two marks or in adjusting an instrument. Such errors are known as **personal errors.**

When several students are doing the same work with the same instrument at the same time, personal error makes the readings a little different. When this occurs, take the mean value. In taking the mean don't increase the number of significant digits. Suppose three of you, working together, read a length as 24·6, 24·8 and 24·5 cm.

Their arithmetic mean is 24·633.... But the physical mean is 24·6 as the mean should have only three significant digits.

1-5. Errors in reading instruments and Percentage error : It is useful to have some idea of the error in the last digit in the readings of different instruments. We give below a list of such values. They hold approximately. In skilled hands, the error will be less. An unskilled worker may have more error.

Instrument	*Approximate error*
Metre scale (graduated in millimetres)	0·5 mm
Silde callipers (Vernier constant$=0{\cdot}1$ mm)	0·05 mm
Screw gauge (Least count$=0{\cdot}01$ mm)	0·01 mm
Common balance	0·02 g (Depends on sensitivity)
Thermometer (graduation in 1 C deg)	0·2°C
Stop clock (1 second graduations)	0·5 second

The approximate errors we have listed above are known as *absolute errors.* The ratio of the absolute error to the value measured in called the *fractional error* in the value. *Percentage error* is the fractional error expressed in percents.

Percentage error : The percentage error in the vaue of a quantity will be smaller the larger the quantity is. Suppose a length measures 50 cm. If the error in the measurement is 0·5 mm, the

$$\text{percentage error}=\frac{0{\cdot}5\text{mm}}{50\text{ cm}}\times 100=0{\cdot}1\,\%.$$

But if the length is 5 cm, the percentage error, calculated as above, will be 1%, which is ten times the above value. So, the larger the quantity to be measured, the less the percentage error.

1-6. Significant digits in addition, subtraction, multiplication and division : This may be realized from actual arthmetical operations. Examples are given below. In all cases the last digit is uncertain.

(*i*) *Addition*

1·234
0·0032
2·5

3·7372

(The sum has only two significant digits. It should be written as 3·7)

(*ii*) *Subtraction*

156·23 (5 significant digits)
125·7 (4 significant digits)

30·53 (3 significant digits)

(The difference should be written as 30·5) (*iii*) *Multiplication*

1.23(3 significant digits)
1.2 (2 significant digits)

246
123

1.476 (2 significant digits)

(*iv*) *Division*

1235 (4 sig. dig.)÷234 (3 sig. dig.)
234)1235(5.27 (3 significant digits in the quotient)
1170

650
458

1820
1638

182

In a multiplication or a division, the number of significant digits in the product or quotient is equal to the smallest number of significant digits in the numers to be multiplied or divided.

Use of approximation in the last significant digit. In mathematical operations, if you find that the figure following the last significant digit is 5 or more, increase the digit by 1. If it is less than 5, leave the last significant digit unchanged. Examples : (*i*) $25{\cdot}5 \times 2{\cdot}3 = 59{\cdot}65$. It should be written as 60. (*ii*) $24{\cdot}5 \times 2{\cdot}3 = 56{\cdot}35$. It should be written as 56.

When a digit in a number is uncertain, the next digit has no sense, and should not be retained in calculating results.

1-7. Graphs. In some experiments you are required to draw a graph or to use a graph for calculating the result. In the experiments we are concerned with, instructions have been given about how to draw the graphs. Some general instructions may be given here.

(*i*) Wherever possible, try to get **straight line graphs.** For example, in Boyle's law, instead of drawing P vs. V(*i.e.* P-V) graph, draw a P vs. $1/V$ graph. This latter will be a straight line. The former (PV=const) will be a rectangular hyperbola. In the case of the simple pendulum, instead of drawing an l—T graph, which is a curve, draw an l—T^2 graph. It is a straight line. Straight line graphs are easier to draw. Besides, they immediately show how good (or bad) your work has been. In good quality work, the points will lie on a straight line. If the graph is a curve you cannot say by looking at the curve if your work has been really good.

(*ii*) Mark the axes of the graph and state what quantity each represents.

(*iii*) Either mark the values of the quantity along the axis at suitable intervals, or state how many small squares of the graph represent a unit of the quantity. The former is better.

(*iv*) The points plotted on the graph should be marked by a cross (×), or by a dot (·) surrounded by a small circle. You need not write the co-ordinates of the point on the graph. It gives the graph a clumsy look, and is unnecessary if you have followed the last instruction.

(*v*) Choose units along each axis so that the larger part of the graph paper is utilized. But in doing so don't choose inconvenient units. (1, 2, 4, 5 or 10 small divisions may conveniently represent one unit, but not 3, 6 or 7.)

(*vi*) To draw a graph, you should preferably plot at least 5 points. If is is a straight line, use a transparent, plastic scale to draw the line. It should pass through as many points as possible. Points which do not fall on the line should be evenly distributed on two sides of the line.

If the graph is a curve, join them by a smooth curved line. A smooth curve is one in which there is no sharp angle between successive sections. Points which do not fall on the curve should lie evenly on two sides of it.

1-8. Honesty in experiment. In some experiments, such as the determination of the acceleration due to gravity, the result is a known one. In verifying Boyle's law, one knows from the beginning that the product PV should be constant. In doing an experiment of this kind, that is, one in which the result or the conclusion is known, you may find that one or more of your readings do not lead to the expected result. Some students may then be tempted to alter the readings so as to fit the result. This is a weakness to which no one should yield. If you do so, you cheat yourself and your teacher and defeat the purpose of training. Besides, you allow your self-confidence to be lowered.

Remember that in obtaining the standard results (such as the value of g, the constancy of the product PV, etc.) much finer instruments than yours were used, and highly experienced workers measured the quantities over and over again before the results were accepted as standard. The accepted values are the mean values of many such very carefully planned and executed measurements. Nobody expects that with crude apparatus and a few repetitions you will get comparable results. A teacher with a little experience will easily detect a cheating.

Every reading contains an error, and errors in the values of measured quantities combine to produce a greater error in the result. Because of the crudeness of the measuring instruments a beginner works with, and his lack of experience, an error of 1% to 5% may well be present in the final result he gets. With experience he learns how to reduce the errors. The first step in his work is to be able to use the basic measuring instruments properly.

CHAPTER

2

PROPERTIES OF MATTER

2-1. Introductory remarks on 'Properties of matter' experiments : Experiments on the general properties of solids, liquids and gases come under this group. The measurements are confined generally to those of mass, length and time. We shall use c.g.s units for these measurements.

In every case we shall find that we are reading a scale. Sometimes it is the distance between two marks or points that we read with a metre scale. Sometimes we look for the coincidence of the pointer of an instrument with some division mark on its scale, or determine where the pointer stands between two division marks. In some cases, it is enough to measure a length coarsely. In other cases it needs to be measured very accurately. It is therefore necessary for us to get acquainted with different instruments for measuring length, and learn how to use them.

2-1.1. Use of a metre scale. A metre scale carries centimetre graduation marks from 0 to 100. Each centimetre is divided into 10 millimetres. The centimetre marks are longer than the millimetre marks. (1mm=0·1 cm.)

In measuring the length of a body, keep the graduation marks of the scale as close to it as possible (Fig. 2.1*a*). Do not place the zero end of the scale in contact with one end of the distance to be measured. Sometimes the zero end of a scale is worn out by use. So the exact position of its zero becomes uncertain.

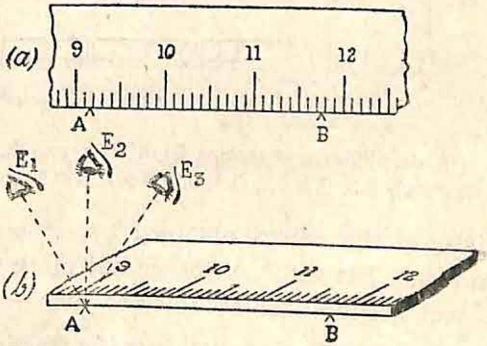

Fig. 2.1 (Showing proper use of a metre scale. (*a*) is proper. Position E$_2$ in (*b*) is proper.)

Look perpendicular to the scale when taking a reading. Otherwise you get a wrong value (Fig. 2.1 *b*).

2-1.2. Eye estimation : Often one end of the length to be measured lies between two marks of the scale. We may try to estimate the additional fraction of a division in our length by *guessing* how much this may be. The estimated fraction may not be correct. But the estimate gives a closer approximation to the length than when it is ignored. Persons may differ in their estimate of this fraction. Try, for example, to estimate the distance between the left tall mark and the short mark as a decimal fraction of the distance between the two tall marks in the small diagrams of Fig. 2.2(*a*). Note your estimates on a piece of paper. Ask your friend to do the same. Then compare your records and check them against the values given below the figure.

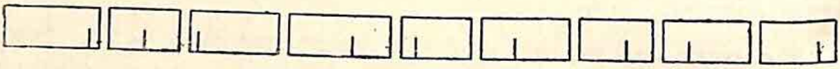

Fig. 2.2(*a*) (Test of eye-estimation)

[In the different diagrams from right to left, the fractions to be estimated are respectively 0.8, 0.3, 0.7, 0.4, 0.2, 0.6, 0.1, 0.5 and 0.9.]

In Fig. 2.2(*b*) the distances are smaller. Make similar estimates of the position of the small mark and check the values. For smaller divisions the values obtained by eye-estimation are sometimes less correct. The width of the middle mark (say the width of the pointer of scale) reduces the accuracy of your estimate.

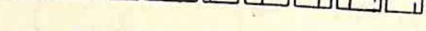

Fig. 2.2(*b*) (Test of eye-estimation)

(In the different diagrams from right to left, the fractions to be estimated are respectively 0.8, 0.3, 0.7, 0.4, 0.2. 0.6, 0.1, 0.5 and 0.9.)

It is not difficult to estimate if a fraction of a millimetre is less than or greater than 0·5 mm. A closer estimate requires experience. That is why we have put down 0·5 mm as the approximate error in reading a metre scale (Section 1-5).

2-1.3. The vernier scale. The required fraction of the smallest division can be determined more accurately with an auxiliary scale, called the *vernier scale*. There are two types of vernier: (1) Straight and (2) Circular. The straight vernier is used to measure the lengths while the circular vernier is used to measure angles.

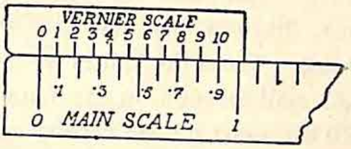

Fig. 2.3 (Vernier sale)

To use a vernier at first we are to determine the *vernier constant* or *the least count of the vernier*. It is the difference between one main scale division and one vernier division. In general if there are n divisions of the vernier scale, it will be equal to (n-1) divisions of the main scale. So the vernier constant ((V.C.)=1 main Scale division-1 vernier division. Since n vernier divisions is equal to (n-1) main Scale divisions, So 1 vernier division is equal to $\frac{n-1}{n}$ main scale divisions.

$$\text{So V. C}=1 \text{ m.s.d.} - \frac{n-1}{n} \text{ m.s.d.} = \frac{1}{n} \times \text{scale division.}$$

In simple straight verniers nine divisions of the main scale are divided into ten equal divisions on the vernier scale (Fig. 2.3).

The vernier scale slides along the main scale, graduated in cm. or in inch. One end of the body whose length is to be measured is placed at the zero end of the main scale. The vernier scale is then moved so as to touch the other end of the body (Fig. 2.4).

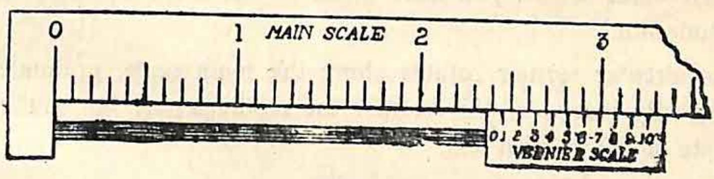

Fig. 2.4 (Use of vernier scale)

How to use a straight vernier scale.

(*i*) Note the value of the smallest division of the main scale. (Suppose it is 1 mm.)

(*ii*) Find how many main scale divisions are equal to an integral number of vernier divisions. (Suppose 9 main scale divisions=10 vernier divisions.)

(*iii*) Find what fraction of a small scale division the difference 1 m.s. division -1 v.s. division is. This difference is the **vernier constant.** From the values we have taken above, we find

A small division on the main scale=1 mm.

10 divisions on the vernier scale=9 divisions on the main scale.

1 vernier division=9/10 main scale division=0·9 mm.

Thus, the vernier constant $=1$ m.s. div. -1 v.s. div.

$=1$ mm$-0·9$ mm$=0·1$ mm$=0·01$ cm.

(*iv*) To measure the length of a body (the rod in Fig. 2.4) place one end of the body at the zero of the main scale, and slide the vernier so that it touches the other end.

(*v*) Find what division mark of the main scale the zero of the vernier has crossed. (In Fig. 2.4, it is the 2.3 mark.)

(*vi*) To find the additional fraction of the main scale division, see where a vernier division mark agrees with a main scale division mark. (In Fig. 2.4, it is at the 6 division mark of the vernier.)

(*vii*) From this we find that the zero of the vernier is ahead of the last main scale division mark by 6 units of the vernier constant (that is, by $6\times0·1$ mm$=0·6$ mm$=0·06$ cm). So the length to be measured is 2·3 cm$+$0·06 cm$=$2·36 cm.

What value would you have given to the fractional division by eye-estimation?

The circular vernier rotates along the main scale, graduated in degrees. By means of this vernier the readings may be read up to a minute of arc or even less.

How to use a circular vernier scale

(*i*) Note the value of the smallest division of the main scale (Suppose it is $0·5°$).

(*ii*) Find how many main scale divisions are equal to an integral number of vernier divisions. (Suppose 29 main scale divisions=30 vernier divisions).

(*iii*) Find what fraction of a small scale division the difference 1 m.s. division -1 v.s. division is. This differencs is vernier constant. From the values we have taken above, we find

30 divisions on the v.s.=29 divisions on the m.s.

$$1\text{ v.d.}=\frac{29}{30}\text{ m.s.d.}=\frac{29}{30}\times 0{\cdot}5^\circ$$

$$\text{Thus v.c. }=1\text{ m.s.d. }-1\text{ v.d. }=0{\cdot}5^\circ-\frac{29}{30}\times 0{\cdot}5^\circ$$

$$=\frac{1}{30}\times 0{\cdot}5^\circ=\frac{1}{60}\text{ degree.}$$

So the reading is correct upto 1′,

2-2. Experiment 1(a) : To determine the volume of a rectangular parallelopiped or a cylinder with the help of a slide callipers.

Theory : The space occupied by a body is called its volume. If *l*, b and h are the length, breadth and height of a paralllopiped then its volume is $l\times b\times h$. The length, breadth or height=[main Scale reading+vernier reading×vernier constant] ±Zero error.

[If d be the diameter of the solid cylinder and *l* its length then volume of the cylinder$=\frac{1}{4}\pi d^2 l$. The length or diameter=(main scale reading+vernier reading×vernier constant)±zero error.]

Apparatus : Slide callipers, a rectangular parallelopiped or a cylinder.

[Description of a slide callipers and directions for the experiment :

Slide callipers (Fig. 2.5) can measure lengths up to about 10 cm with an accuracy of 0·1 mm using a vernier scale (V). V slides along the main scale S. The nut N fixes the vernier at any desired place. The method of use is described below.

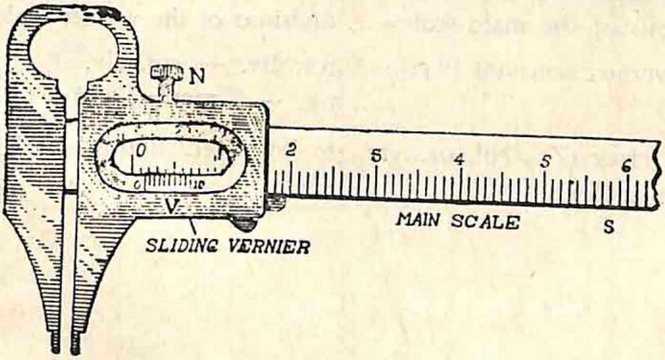

Fig. 2.5 (Slide calipers)

(1) Loosen the nut N and put the jaws in contact. If the zeros of S and V do not agree in this position, the instrument has a 'zero error'. If the zero of the vernier lies more towards the fixed jaw than the zero of the main scale, the amount by which it is nearer should be noted. This value should be added to the apparent reading of a length to get the correct length. If the O of V lies on the other side of the 0 of S, the distance between the two zeros has to be subtracted from the apparent reading.

(2) Find the vernier constant in the way described in Section 2-1.3. Note the 'zero error', if any, stating by its side whether it should be *added* to or *substracted* from the apparent reading.

(3) Move the jaws and place between them the body whose length is to be measured. One end of the body will rest against the fixed jaw and the other against the movable jaw attached to the vernier. Fix the vernier in this position using the nut N.

(4) Take the reading corresponding to the zero of the vernier in the way described in Sec. 2-1.3. Add or subtract the zero error as required to find the final length.]

Observations

(*i*) Vernier constant of the slide-callipers:

Each small division of the main scale =...mm

...divisions of the main scale=... divisions of the vernier scale.

∴ vernier constant (v.c.) =1 m.s. div. −1 v.s. div.

=...mm − ...mm=...mm= ... cm.

Zero error (Z)=Nil, or...cm. (to be added/subtracted) (keep the one applicable) (*ii*) Measurement of length, breadth and height (or diameter and length).

Dimension	No. of obs	Main Scale reading in cm. (a)	Vernier reading (b)	Value of the Vernier reading in cm. (b)×v.c.=(c)	Total reading in cm. (a)+(c)	Mean reading in cm. (m)	Corrected reading in cm. (m±z)
Length	1. 2. : etc.	4·8	7	7×·01=·07	4·87		
Breadth	1. 2. : etc.						
Height	1. 2. : etc.						
Diameter.	1. (*a*) (*b*) 2. (*a*) (*b*) etc.						

Note : In case of cylinder length and diameter are to be measured.

Calculations

The volume of the rectangular parallelopiped

$= l \times b \times h = \ldots \times \ldots \times \ldots \times \ldots = \ldots\ldots \text{ cm}^3.$

[The volume of the cylinder $= \frac{1}{4}\pi d^2 l \text{ cm}^3$]

Method followed

(*i*) The zero error of the instrument was noted.

(*ii*) The vernier constant of the instrument was calculated.

(*iii*) The body was placed between the jaws and readings of the main scale and vernier were noted.

(*iv*) The readings were taken at different places and the mean value was calulated. (In case of a cylinder the readings of diameter at two mutual perpendicular directions were noted.)

(*v*) Then the volume of the body was calulated.

Precautions

(*i*) The jaws should not be pressed hard. It will derease the dimension to be measured.

(*ii*) For diameter two readings corresponding to two mutual perpendicular directions in the same diametral plane should be noted.

Oral Questions and answers :

(1) **Q.** Why vernier is used? **Ans.** By vernier we can measured a very small length, even smaller than the smallest scale division accurately.

(2) **Q.** Why in measuring diameter of a cylinder two readings at right angles to each other at a place are taken? **Ans.** To avoid the error arising due to non-uniformity of the cross-section of the cylinder.

(3) To find the volume of a cylinder the diameter of the cylinder should be measured very accurately—why? **Ans.** The diameter of the cylinder occurs in 2nd. power and so it should be measured very accuretely otherwise a small error in the measurement of diameter will increase the error in calculating volume.

Experiment 1(b) : To determine the cross-section of a wire by screw gauge.

Theory : If d be the diameter of a wire, then its cross-section is given by $\frac{1}{4}\pi d^2$. The diameter d=[linear scale reading+circular scale reading × Least count] ±Zero error.

Apparatus : Screw-gauge, wire.

Description of screw-gauge

It is an instrument for measuring lengths of about 2-3 cm with an accuracy of 0·001 cm or 0·002 cm. Its essential part is a finely cut, uniform screw of 'pitch' equal to 1 or 0·5 mm. (Pitch is the distance between two successive threads of a screw.) When the screw is given a single, full turn, its head moves forward or backward by an amount equal to the pitch.

The **construction** of the instrument is shown in Fig. 2.6. The screw (Sc) can move through a similarly cut tube A attached to one arm of a U-shaped piece of steel. A line L runs along the tube A parallel to its axis, and hence to the axis of the screw. It is called the 'reference line'. A millimetre (or half millimetre) scale is etched along it. The scale is called the *linear scale*.

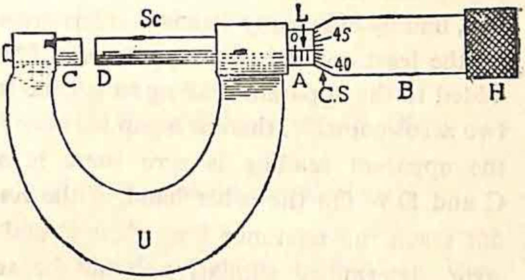

Fig. 2.6 (Screw gauge)

Outside A there is another tube B. Its end near the U is bevelled (=sloping). The circumference of this end is divided into 100 (or 50) equal parts. It is called the *circular scale* (C. S). The other end of B is attached to the screw. When the head H of the screw is turned, the screw moves and the circular scale (C. S.) advances or retreats along the linear scale L.

The end D of the screw is perpendicular to the line L. Opposite D, there is a similar parallel surface C at the end of a stud attached to the other arm of the U. In an instrument which has no 'zero error', both the linear and the circular scales read zero when D touches C. If the two zeros do not coincide, there is a zero error.

If the pitch of the screw is 1 mm and the circular scale has 100 divisions, then the screw head moves by 1/100 mm=0·01 mm when the circular scale turns through one division. The amount by which the screw head moves when the circular scale turns through only one division is called the **least count** of the instrument.

$$\text{Least count}=\frac{\text{Pitch of the screw }(p)}{\text{Number }(N)\text{ of divisions on the circular scale}}.$$

[If pitch=1 mm and C.S. has 100 div.s., least count=0·01 mm.
If pitch=1 mm and C.S. has 50 div.s., least count=0·02 mm.
If pitch=$\frac{1}{2}$ mm and C.S. has 50 div.s., least count=0·01 mm.]

Zero error. Always examine your screw gauge for zero error before use. Turn the head H so that D touches C *softly*. *Don't press H hard.* It damages the screw and increases the zero error. If you find that the zero of the circular scale has crossed the reference line, find by how many divisions it has done so. This number multiplied by the least count is the zero error. This kind of zero error must be added to the apparent reading to get the true reading. (For when the two zeros coincide, there is a gap between C and D. This means when the apparent reading is zero there is an actual distance between C and D.) On the other hand, if the zero of the circular scale does not reach the reference line when C and D are in contact, the zero error, determined similarly, should be subtracted from the apparent reading.

[Directions for the experiment.

(*i*) *Find the pitch of the screw.* To do so bring the zero of the circular scale on the reference line and give H four (or n) complete turns. Find how many divisions (l) the bevelled head moves on the linear scale. See what each division of the linear scale means. You now have data for calculating pitch.

$$\text{Pitch} = \frac{\text{Displacement on linear scale}}{\text{Number of turns}}.$$

(*ii*) See how many divisions (N) the circular scale has (100 or 50).

(*iii*) *Calculate the least count* (Pitch/N).

(*iv*) *Determine zero error, if any.* Record it as 'nil' if there is none. Otherwise note the value and write 'to be added' or 'to be subtracted' as the case may be.

(*v*) Increase the gap CD. Place between them the body whose length is to be measured and turn H so that C and D *lightly* touch the two ends of the body.

(*vi*) Note the reading exposed on the linear scale. (It is 2 in Fig. 2.6).

(*vii*) Note the circular scale reading which coincides with the reference line L. (It is 43 in the figure.)

(*viii*) Since the pitch and least count are known, add (*vi*) and (*vii*) to get the apparent length. Add (or subtract) the zero error, if any, to get the true length.]

Observations.

Each division of the linear scale=... mm=... cm.

...(n) complete turns of the screw moves it...(l) divisions along the linear scale.

Hence pitch of the screw=...(l)/...(n)=...mm=...cm.

Number (N) of divisions on the circular scale=...

∴ Least count=pitch/N=... mm=... cm.

Zero error (Z)='Nil' or ...cm (to be added/subtracted) (Keep the one applicable.)

[(*a*) and (*b*) are right angles (in the same diametral plane)]

No. of obs.	Linear Scale reading in mm (L)	Circular Scale reading (C)	Value of Circular Scale reading in mm C×L.C. (V)	Apparent diameter in mm (L)+(V)	Mean apparent diameter in mm d′	True diameter in mm d=d′±Z
1. (a)	1·0	43	43×·01=·43	1·43		
(b)	1·0	45	45×·01=·45	1·45		
2. (a)						
(b)						
:						
etc.						

Calculations :

Hence the true diameter of the wire =... mm=... cm.

Result : Cross-section of the wire=$\frac{1}{4}\pi d^2=\frac{1}{4}\times 3{\cdot}14\times(\ldots)^2=\ldots$ Sq. cm.

Method followed :

(*i*) First the pitch, least count and zero error of the instrument were found.

(*ii*) The diametral side of the wire was placed between the gap by turing the Screw to hold the wire lightly between them and both the linear and circular scales were noted.

(*iii*) Another reading at right angles to the first was taken. Did so at different places of the wire.

Precautions.

(*i*) The screw should not be pressed hard. It damages the screw and increases the zero error.

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(*ii*) Two readings corresponding to two mutual perpendicular directions in the same diametral plane should be noted.

(*iii*) The diameter should be measured at least five different places. A small error in measuring d will increase the error in calculating the cross-section, since the diameter occurs in 2nd. power.

(*iv*) Back-lash error should be avoided.

(**Note : Back-lash error :** When a screw fits into a nut there is always some misfit between the two. The misfit is minimum when the instrument is new and gradually increases with use. Due to this wear of the nut and the screw a reversal of the motion of the screw does not take place until it has turned through an angle depending on the extent of the wear. There is thus a lag between the linear and the circular motions when the direction of the motion is reversed. This lag is known as **back-lash** error.

In using a screw-gauge, or any device having a micrometer screw, back-lash error should be avoided. This can be done by turning the screw backward by an amount greater than the back-lash error, and then slowly advancing the screw to touch the object.).

Oral Questions and Answers

(1) **Q.** You are given two Screw-gauges, one of l.c.=0·01 mm and the other of l.c.=0·005 mm. Which one you prefer?

Ans. The second one; because by the 2nd Screw-gauge we can measure upto a length of 0·005 mm accurately.

(2) **Q.** What do you mean by back,-lash error?

Ans. See note of this experiment.

(3) **Q.** Why in measuring diameter of a wire two readings at right angles to each other at a place are taken?

Ans. See oral question of 1(a) expt.

(4) **Q.** To find the cross-section of a wire the diameter of the wire should be measured very accurately-why?

Ans. See oral question of 1(a) Expt.

Experiment 1(c): To determine the thickness of a given glass plate by using spherometer.

Theory : The thickness of a given glass plate is the difference in readings of the test plate and the base plate. The reading of the test plate or base plate=Linear scale reading+circular scale reading × least count.

Apparatus : Spherometer, glass plate.

Description of a spherometer:

The main purpose of a spherometer is to measure the thickness and the radius of curvature of a surface, such as of a spherical mirror or a lens. Its operation is that of the screw of a screw gauge.

Construction. The construction of the instrument is shown in Fig. 2.7. A finely cut screw S passes through a round nut T. which is also cut similarly. Three identical arms are attached to T at equal angles to one another. At the ends of the arms there are three equal fine pointed legs. Their sharp ends A, B, C form an equilateral triangle. The axis of the screw passes through the centre of the triangle formed by A, B and C. The lower end P of the screw is sharp. Its top carries a round disk. The circumference of the disk is divided into 50 or 100 equal divisions. This is known as the *circular scale* (C.S). The screw, with its circular scale, rotate as the head H is trurned. The circular scale moves along a linear scale L, which is graduated in millimetres. The amount by which the screw moves forward or backward can be read with the help of the scales L and C. S. (Compare the screw and the scales of a spherometer with those of a screw gauge.)

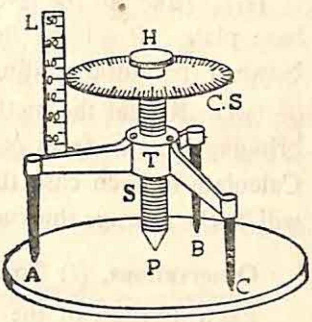

Fig. 2.7 (Spherometer)

[Directions for the experiment.

(*i*) Note the value of each small division on the linear scale. **(It** is 1 mm or 0·5 mm usually.)

(*ii*) Bring the zero of the circular scale into coincidence with some mark on the linear scale. Give the head H four full turns and find from the linear scale the number of divisions by which the disk has moved. Calculate the *pitch* of the screw from these data.

(*iii*) Note the number of divisions on the circular scale. Hence calculate the *least count* of the instrument.

(Note that (*i*) to (*iii*) are the same as for the screw gauge.)

(*iv*) To get the *initial reading*, raise P and place the three points A, B. C on a base plate. place the test plate below P. Now lower P until it just touches the test plate. (This position may be found as follows. Look tangentially along the plate. You will see both P and its image in the test plate. The correct position of P is when it just touches its image. If this position is crossed, the instrument will rock.)

(*v*) In this position read the linear and circular scales. They give you the initial readings.

(*vi*) Take out the test plate below P and move P so as to touch the base plate. Read the linear and circular scales. Let the difference between the initial reading and this reading be t.

(*vii*) Repeat the method at least six different places by alternately bringing the two faces of the test plate in contact with the base plate. Calculate in each case the value of t. The mean of these values of t will be the average thickness of the glass plate.]

Observations. (*i*) To find the least count of the spherometer.

Each division of the linear Scale = ...mm

...(n) complete turns of the Screw moves it...... (l) divisions along the linear scale.

Hence the pitch of the Scnew = ... (l)/ ... (n) = ... mm = ...cm.

Number of divisions on the circular scale=... (N)

∴ Least Count=Pitch/N = ... mm=... cm.

(*ii*) To find the thickness of the given glass plate.

Position of the test plate	No. of obs.	Scale reading when the Screw touches the						Thickness of the plate $h_2 \sim h_1$ in mm.	Mean thickness (t) in mm.
		test plate			base plate				
		Linear scale in mm.	Circular scale in mm (c.s.r × l.c.)	Total h_2 in mm	Linear scale in mm	Circular scale in mm (c.s.r × l.c.)	Total h_1 in mm		
One face	1.								
	2.								
	3.								
	:								
	etc.								
Other face	1.								
	2.								
	3.								
	:								
	etc.								

Result

Hence, the thickness of the given glass plate =... mm=... cm.

Method followed. (*i*) First the pitch, least count were found.

(*ii*) The spherometer was placed on the base plate and by turning the screw the test plate was placed below the screw. By moving the screw downward the screw was just touched the test plate.

(*iii*) In this postion both linear and circular Scales were noted.

(*iv*) The test plate was taken out below the screw and by turning the screw downwards the screw tip was just touched the base plate.

(*v*) Again in this position both linear and circular scales were noted.

(*vi*) The method were repeated three times.

(*vii*) The other face of the glass plate now brought in contact with the base plate and the method were repeated.

(*viii*) From these observations the value of t was calculated.

2-4.2. An alternative method of use of spherometer

In the case of an old instrument, the screw becomes loose in the nut by use. Due to this play between the nut and the screw, the edge of the circular disc may indicate different readings on the linear scale for different tilts of the screw axis. This gives rise to some degree of uncertainty in the linear scale reading. In order to get rid of this difficulty an alternative method of taking readings, as stated below, may be followed.

Theory : Let R be the number of complete rotation of the circular scale and A be the extra number of circular scale division rotated when the screw-tip successively touches the test plate and the base plate, then the thickness of the plate is given by

$$t = R \times N + A \times L.C.$$

where N is the total number of circular scale division and L. C. is the least count of the spherometer.

[**Directions for the experimet :** (*i*) to (*iv*) same as (*i*) to (*iv*) of the previous experiment.

(*v*) In this position read circular scale only.

(*vi*) Take out the test plate below P. Move the screw downwards so as to touch the base plate and at the same time count the number of full rotation of the circular scale (if any). Take the circular scale reading.

(*vii*) Same as (*vii*) of the previous experiment.

(*viii*) While rotating the screw from the first position to the second, notice whether the circular scale reading is diminishing or increasing. Note this over the initial reading in your table. An arrow to the right may indicate an increase (say), and an arrow to the left a decrease.]

Observation : (*i*) To find the least count of the spherometer: Same as (*i*) of the previous experiment.

(*ii*) To find the thickness of the given glass plate.

Position of the glass plate	No. of obs.	Circular scale reading when the screw just touches the test plate (I)→	When the screw just touches the base plate		Additional no. of circular scale rotated 'n' $n=(F-I)$; when $F<I$ $n=[N-(I-F)]$, When $F>I$	Total No. of circular scale rotated $T=R\times N+n$	Thickness of the given glass plate $t=T\times$ l.c. in mm.
			No. of full rotation of the circular Scale (R)	circular scale reading (F)			
One face	1.	48	2	50	2	2×100+2=202	
	2.	49	1	48	100−(49−48)=99	1×100+99=199	
	3.						
	:						
	:						
	etc.						
Other face	1.						
	2.						
	3.						
	:						
	:						
	etc.						

If the circular scale diminishes then $n=[N-(I-F)]$, when $F>I$; and $n=(F-I)$, when $F<I$. Then give arrow to the left,

Result : Mean thickness of the given glass plate=...mm= . cm.

Method followed : (*i*) and (*ii*) same as previous experiment.

(*iii*) In this position the reading of the circular scale was noted.

(*iv*) Same as previous experiment. (*v*) At the same time the number of full rotation of the circular scale and the reading of the circular scale were noted.

(*vi*), (*vii*), (*viii*) Same as previous experiment.

Precautions:

(*i*) The readings should be taken carefully when the screw just touches the surfaces.

(*ii*) Back-lash error should be avoided. (See Screw-gauge experiment.).

Oral Questions and Answers:

(1) **Q.** What is back-lash error?

Ans. See note of expt. 1(b).

(2) **Q.** Why it is not necessary to find the zero-error in case of spherometer as in the case of a screw-gauge?

Ans. In the case of a spherometer we take the difference of two readings which eliminates the error, if there be any.

(3) **Q.** Why the instrument is called spherometer?

Ans. By this instrument we can measure the radius of curvature of a sphrical surface. That is why this intrument is called spherometer.

2-5. Weighing a body with a common balance. A common balance (also called a 'beam balance' or a 'physical balance') measures the mass of a body by comparison with standard weights of known masses.

Masses will be expressed in grams (symbol g) and weights in gram-weights (symbol g-wt). 'Mass' is the amount of matter in a body. 'Weight' means the force with which the earth pulls a body. The 'weight' W of a body of mass m is $W=mg$ where g is the acceleration due to gravity. (Don't confuse the symbol 'g' for gram with the symbol 'g' for the acceleration due to gravity. The former will be printed in erect (Roman) type, and the latter in slant (italics) type. The international symbol for gram is no longer gm; gm has been discarded in favour of g.). It is correct to write g-wt when a weight is expressed in grams. But where there is no confusion, some authors write simply g instead of g-wt. Though not strictly correct, the practice is more or less tolerated. Further, some authors use symbols like kgf (kilogram force), gf (gram force) for kg-wt, g-wt and the like.

Construction of a common balance. It has been shown in Fig. 2.8 and the parts labelled. A description in words will be too lengthy and is unnecessary. (Compare the figure with a common balance in your laboratory. That is a better way of getting familiar with an instrument than through lengthy descriptions.)

The common balance can ordinarily weigh a body with an accuracy of 0·01g. For greater accuracy 'chemical balances' using 'riders' are used.

Using a common balance.

(*i*) Lift the front door of the glass case of the balance, and see if it remains fixed in position. (Some balance may have two side doors only.)

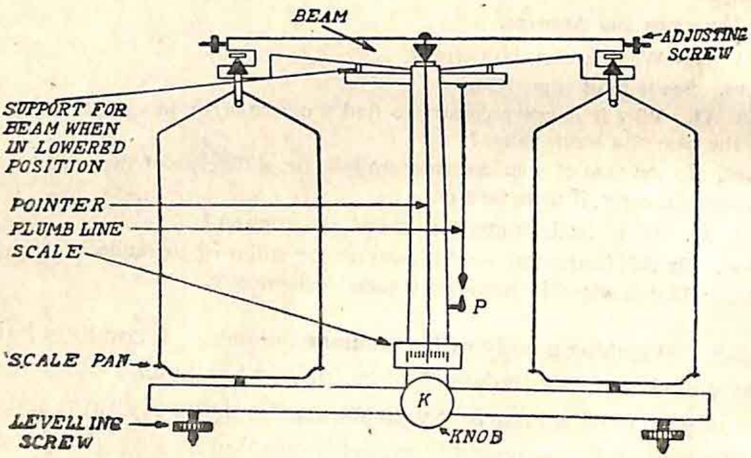

Fig. 2.8 (Common balance)

(*ii*) See if the plumb-line hangs exactly vertically over the point P. If it does not, the balance beam will not be horizontal. The levelling screws should then be adjusted to bring the plumb line just over P.

(*iii*) Except during weighing, the balance beam rests on its 'support', and cannot swing. The balance beam can be lifted from its support by turning the handle (or knob) K. If all adjustments have been correctly made, the pointer of the balance will oscillate symmetrically about the zero of the scale. If it does not, move the adjusting screws at the ends of the beam till the pointer moves symmetrically. The balance is now ready for use.

(*iv*) Turn K so that the balance beam rests on its support. Place the body to be weighed on the left scale pan. Keep the weight box to your right near the right scale pan. [Left-handed students will do the opposite.]

(*v*) Place the heaviest weight from the weight box on the right pan and turn K, lifting the beam. See which side is heavier. Decrease or increase the weights *systematically* till the pointer oscillates symmetrically on the scale. *While adding or removing a weight, bring the beam to rest on the support. Lift the weights with the tongs provided in the weight box. Don't handle the weights with your fingers.* (Don't forget these precautions.)

(*vi*) When the weight of the body has been balanced, record the value of each of the weights on the right pan and add them up before removing them. Then transfer the standard weights to the weight box one by one, and make a tick mark on the corresponding value on your record.

(*vii*) Close the front door, and leave everything as you found them.

Precautions in use.

(*i*) In weighing, each student should work individually.

(*ii*) Use tongs in handling the standard weights, never your fingers.

(*iii*) Don't weigh a wet body, nor a hot body.

(*iv*) To weigh a granular substance, keep them on a weighed watch glass or any other suitable vessel of known weight.

(*v*) Do not change weights unless the beam is on its supprt.

2-6. Hydrostatic balance. A *hydrostatic balance* means a balance adapted for weighing a body both in air and in a liquid. Years ago, a hydrostatic balance was like a beam balance with a short pan. Below this pan a hook was attached. But now balances of such special construction are unnecessary. The common balance, described earlier, has an extra hook below the point where the scale pan is suspended from the beam (Fig. 2.9). The body to be weighed in, say, water, is suspended by means of a fine thread from this hook. A wooden bridge can be placed across the pan below (see figure) without touching the pan. A beaker containing water can be placed on the bridge.

The hanging body is first weighed in air. Then the bridge and the beaker are placed below the body, with the body hanging inside the beaker without touching its sides or bottom. Water is then poured into the beaker so as to keep the body immersed even when the balance beam is raised. It is then weighed again, fully immersed in water (or any liquid).

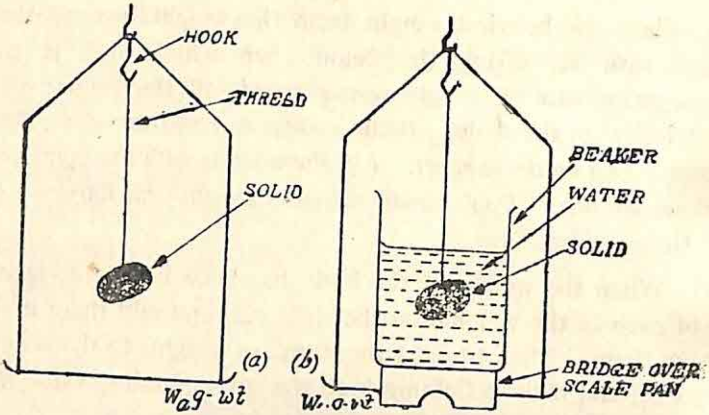

Fig. 2.9 (Steps in determining specific gravity)

Mentioning a hydrostatic balance for the determination of specific gravity means the application of Archimedes' principle and the use of a common balance.

2-7. Experiment No. 2.

To determine the volume of a given solid of irregular shape, heavier than and insoluble in water by Hydrostatic balance.

Theory : Archimedes' principle states that a body fully immersed in water at rest loses a part of its weight equal to the weight of the displaced water. The displaced water has the same volume as the volume of the body.

When a body is weighed in air and in water (fully immersed), the difference between the observed weights is equal to the weight of the water displaced by the body.

If the weight of the body in air $=W_a$ g-wt., and its apparent weight when fully immersed in water $=W_w$ g-wt., then (W_a-W_w) g-wt. is the weight of the water displaced.

Now, the weight of 1 cm^3 of water is equal to the weight of a one gram mass.

$\therefore$ Volume of water displaced $=(W_a-W_w)$ cm^3. But this is also the volume of the solid.

$\therefore$ Volume of the solid $V=(W_a-W_w)$ cm³.

Apparatus : The experimental solid, balance with weight box, wooden bridge, beaker, water, thin thread (preferally water-proof.).

[Directions for the experiment :

(1) Check if the balance is in order. If it is not, report it to your teacher. (Later, when you get more experience, you may be allowed to set it right yourself.)

(2) Place the bridge across the left pan and see if the balance can oscillate freely without touching the bridge.

(3) Place the beaker on the bridge below the hook above.

(4) Suspend the body under investigation from the hook so that it is about 2-3 cm above the bottom of the beaker and is in the middle of it. The body must not touch the beaker.

(5) Weigh the body in air, and record the weight (W_a g-wt).

(6) Pour enough water into the beaker so that the body remains fully immersed even when the beam is lifted for weighing.

(7) Note if there are any air bubbles sticking to the body. If there are bubbles they must be removed with a thin wire. (Bubbles increase the volume of the displaced water.)

(8) Weigh the body fully immersed in water and record the weight (W_w g-wt.)

(9) Leave things as you found them.]

Observations: Room temperature = ...°C

No. of obs.	Weight of the body in air. (W_a)	Weight of the body in water (W_w)	Volume of the body $V=(W_a-W_w)$ cm³.	Mean Volume in cm³.
1.	(..+..+..+..)g.-wt +(..+..+..+..)mg-wt =..g-wt	(..+..+..+..)g-wt +(..+..+..+..)mg-wt. =..g-wt.		
2.				

Result. The required volume of the given body=...cm³.

Method followed :

(1) The balance was checked and found to be in order.

(2) The bridge was placed across the left pan and the beaker on

it. The body was suspended from the hook above the pan so as to be in the centre of the beaker.

(3) The body was weighed in air.

(4) Water was poured into the beaker. The body was weighed while fully immersed in water.

Precautions :

(1) The scale pan never touched the bridge during weighing.

(2) The body never touched the beaker during weighing.

(3) No air bubbles stuck to the body.

Oral Questions and answers.

(1) **Q.** State Archimedes' principle.

Ans. A body wholly or partly immersed in a fluid at rest appears to lose a part of its weight, which is equal to the weight of the displaced liquid.

(2) **Q.** How have you applied it to find the volume of a body?

Ans. See theory of this expt.

(3) **Q.** What is the harm if air bubbles stick to the body?

Ans. Bubbles increase the volume of the displaced watei and values of $(w_a - w_w)$, there by giving a increase value of V.

(4) **Q.** What is the harm if the pan touches the bridge or the body touches the beaker?

Ans. We do not get the correct value of w_a and w_w.

2-8.1. Experiment 3

To determine the specific gravity of an insoluble solid, heavier than water, with a hydrostatic balance.

Theory. Specific gravity of a substance is defined as the ratio of the mass (or weight) of a substance to the mass (or weight) of an equal volume of water at its maximum density i.e. at 4°C. According to definition,

$$\text{Specific gravity} = \frac{\text{Weight of a given volume of the substance}}{\text{Weight of an equal volume of water at } 4^\circ\text{C}}$$

If weight of a body in air $= W_a$ g-wt, and

its weight in water $= W_w$ g-wt, then $(W_a - W_w)$ g-wt

is the weight of the displaced water, that is, of an equal volume of water. Hence the specific gravity s' of the material of the body at room temperature is given by

$$s' = \frac{W_a}{W_a - W_w}$$

Hence true sp.gr. $S = S' \times S_t$ where S_t is the sp.gr. of water at room temperature.

Apparatus. The experimental solid (a piece of glass, marble or metal), balance (with weight box), wooden bridge, beaker, water, thin thread (preferably waterproof).

[Directions for the experiment: Same as experiment 2]

Observations. Room temperature (t) =... °C

Sp. gr. of water at room temperature (S_t)=...

No. of obs.	Weight of the body in air W_a	Weight of the body in water W_w	Sp. gr. $S' = \frac{W_a}{W_a - W_w}$	Mean S'
1.	(...+...+...+...)g-wt. +(...+...+...+...)mg-wt. =...g-wt.			
2.				

Calculations. The specific gravity at room temepratureis

(1) $s' = \dfrac{W_a}{W_a - W_w} = \dfrac{\text{...g-wt}}{\text{...g-wt}} = \ldots$ (2)...;

Result. The required true specific gravity=$S' \times S_t$=...

Method followed : Same as experiment 2.

Precautions: Same as experiment 2.

Remarks on temperature correction of specific gravity.

According to the definition of specific gravity, the water should be at 4°C, the temperature at which water has maximum density. But the water used is at room temperature. This temperature varies from about 20°C to 40°C throughout the year. At 40°C the specific gravity of water (relative to that at 4°C) is 0·992. It differs from unity by about 8 parts in 1000 (that is, by about 1%). At lower temperatures, the difference is less. At 20°C, the specific gravity of water is 0·998. This differs from unity by 2 parts in 1000 (0·2%).

Unless, therefore, both the numerator (W_a) and the denominator ($W_a - W_w$) in the expression for specific gravity contain at least *four significant digits each*, it is unnecessary to make any temperature correction. With three significant digits in the denominator, the third digit in the result is uncertain. It will remain so even if correction is made for the temperature of the water used.

To apply the temperature correction multiply the result (s') obtained by the specific gravity (s_t) of the water used. For apparent

$$\text{sp.gr. } s' = \frac{\text{weight of a volume } V \text{ of the meterial}}{\text{,,} \quad \text{,,} \quad V \text{ of water at } t^\circ\text{C}}$$

$$= \frac{\text{weight of a volume } V \text{ of the material}}{\text{,,} \quad \text{,,} \quad V \text{ of water at } 4^\circ\text{C}}$$

$$\times \frac{\text{weight of a volume } V \text{ of water at } 4^\circ\text{C}}{\text{,,} \quad \text{,,} \quad \text{,,} \quad \text{at } t^\circ\text{C}}$$

$$= \text{true sp.gr. } (s) \times \frac{1}{s_t}$$

Or true specific gravity $s = \text{app. sp. gr. } s' \times s_t$

Sp gr of water at different temperatures (°C)

Temp.	0	2	4	6	8
20	0.9982	0.9978	0.9973	0.9968	0.9963
30	0.9957	0.9951	0.9944	0.9937	0.9930

Oral Questions and answers:

Q. 1. What is the difference between density and specific gravity? What are their units? In what system of unit are the numerical values of the two quantities the Same?

Ans. Density means mass per unit volume. sp. gr. is the ratio of the density of the substance to the density of some standard substance, generally pure water at 4°C. So sp. gr. is relative density and is a pure number. Unit for density is unit of mass/unit of volume (g/cm^3 in cgs units). The numerical values of the two are equal in cgs unit.

Q. 2. In this case what is the density of the body in cgs units.?

Ans. If s is the sp. gr. then density is s g/cm^3.

Q. 3. What is the volume of the body?

Ans. ($W_a - W_w$) Cm^3.

Q. 4. What is the harm if the thread soaks water or is thick?

Ans. When the body is in water its weight will be greater than the true weight due to the water absorbed by the suspension thread. If the thread is thick W_a increases due to the weight of the suspension thread.

2.8.2. Experiment 4

To determine the specific gravity of a solid, soluble in water but heavier, with a hydrostatic balance.

Theory. If the weight of a solid in air is W_a and its weight in a liquid in which it does not dissolve is W_l, then the specific gravity s_t

of the solid relative to the liquid as standard is given by

$$s_l = \frac{W_a}{W_a - W_l}$$

If the specific gravity of the liquid relative to water is s', then the specific gravity s_1 of the solid relative to water as standard at room temperature ($t°c$) is given by

$$s_1 = s_l \times s'$$

$\therefore$ True Sp. gr.$=S_1 \times S_t$ where S_t is the Sp. gr. of water at t°c.

Apparatus. Experimental solid (a lump of alum, rock-salt or sugar-candy); kerosene (it does not dissolve the solid); common balance with weight box; wooden bridge; beaker; thin thread.

[**Directions for the experiment.**

All directions same as Experiment 2, except that 'kerosene' is to be read for 'water'.]

Observations.

Room temperature (t°C) = ... °C

Sp. gr. of water at t°C. = ...

Given Sp. gr. of Kerosene relative to water. (s')=...

No. of obs.	wt. of the solid in air W_a g-wt.	wt. of the solid in kerosene W_l g-wt.	sp. gr. of solid relative to kerosene	Mean sp. gr. relative to kerosene (S_l)
1.				
2.				

Calculations. Sp. gr. of the solid relative to kerosene (s_l)

$$= \frac{W_a}{W_a - W_l} = \ldots$$

Result. $\therefore$ Sp. gr. of solid relative to water ($=s_l \times s'$) at t°c

$$= \ldots \times \ldots = \ldots$$

$\therefore$ True Sp. gr. ($=S_1 \times S_t$) $= \ldots \times \ldots = \ldots$

Method followed.

[(1) to (4)—as in the experiment 2, except that you write 'kerosene' for 'water'.]

(5) The product of the sp. gr. (s_l) of the solid relative to kerosene and the sp. gr. s' of kerosene relative to water gives the apparent value (s_1). Hence true Sp. gr. was calculated.

Precautions.

[As in Experiment 2]

Temperature correction.

[As in Experiment 3]

Oral questions and Answers:

Q. 1. What is the volume of the body?

Ans. Volume of $(W_a - W_l)$ grams of Kerosene $=(W_a - W_l)/S_l$ cm.^{3}

Other questions same as in expts. 2 & 3.

2.8.3. Experiment 5

To determine the specific gravity of a soild, insoluble in water and which floats in water, with a hydrostatic balance.

Theory. Let the

Weight of the solid in air $= W_1$ g-wt;

Weight with the solid in air and sinker in water $= W_2$ g-wt.

Weight of the solid+sinker, both in water $= W_3$ g-wt.

Then, by Archimedes' principle, the weight of the water displaced by the solid is $(W_2 - W_3)$ g-wt. The volume of this amount of water is equal to the volume of the solid.

$$\therefore \text{ The apparent sp. gr. } (s') = \frac{W_1}{W_2 - W_3}$$

$\therefore$ True Sp. gr. $= S' \times S_t$ where S_t in the Sp. gr. of water at room temperature.

(Note: A *sinker* is a body heavier than water. When tied to the lighter body it makes the latter sink in water).

Apparatus. Experimental solid (cork, light wood or a piece of light plastic); common balance; weight box; wooden bridge; beaker; sinker (a brass weight or a piece of glass or stone which when tied to the solid sinks together in water); fine thread; water.

[Directions for the experiment.

(1) Suspend the solid from the hook and weigh it in air. (Fig. 2.10*a*).

(2) Tie the sinker to the solid and weigh with the solid in air and the sinker in water. (Fig. 2.10*b*)

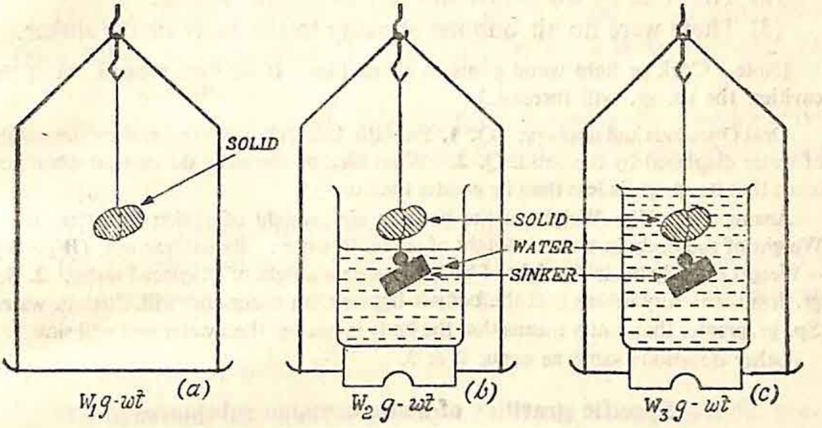

Fig. 2.10 (Steps in determining specific gravity)

(3) Weigh the body and the sinker both in water. (Fig. 2.10*c*)]

Observations.

Room temperature (t°c) =...

Sp. gr. of water at t°c (S_t) =...

No. of obs.	Wt. of the Solid in air w_1g-wt.	Wt. of the Solid in air +Sinker in water w_2g-wt.	Wt. of the Solid and sinker, both in water w_3g-wt	Apparent sp. gr. S′	Mean S′
1.					
2.					

Calculations and Result.

The apparent sp. gr. of the solid $(s') = \frac{W_1}{W_2-W_3} = ...$

The true Sp. gr. $S = S' \times S_t = ...$

Method followed.

(1) to (3)—as in Experiment 2.

(4) The sinker was tied to the solid so that a distance of 2-3 cm was left between them.

(5) Water was poured into the beaker so as fully to cover the sinker, leaving the solid in air. W_2 was taken in this condition.

(6) More water was poured into the beaker so as to cover the body also. W_3 was taken in this condition.

Precautions.

(1) The pan did not touch the bridge.

(2) The solid or the sinker did not touch the beaker.

(3) There were no air bubbles sticking to the body or the sinker.

[**Note.** Cork or light wood contains air cavities. If air were pressed out of the cavities, the sp. gr. will increase.]

Oral Questions and answers: **Q. 1.** Explain how (W_2-W_3) represents the weight of water displaced by the solid. **Q. 2.** What idea of the solid do you get when you learn that its sp. gr. is less than or greater than unity?

Answers. 1. W_2=Weight of the body in air+weight of sinker in water. W_3= Weight of the body in water+weight of sinker in water. By subtraction, (W_2-W_3) =Weight of body in air—weight of body in water=weight of displaced water. 2. Sp. gr. less than unity means that the body is lighter than water and will float in water. Sp. gr. greater than unity means that the body is heavier than water and will sink.

Other questions same as expts. 2 & 3.

Specific gravities of some common substances

Substance	Sp. gr.	Substance	Sp.gr.
Aluminium	2·70	Sodium Chloride	2·17
Alum (Potassium)	1·76	Sand	2·63
Brass	8·4-8·7	Steel	7·7-7·9
Copper	8·93	Sugar	1·59
Cork.	0·22-0·26	Ethyl alcohol	0·792
Glass (Crown)	2·5-2·7	Glycerine	1·26
,, (Flint)	2·9-4·5	Kerosene	0·80
Iron (Cast)	7·0-7·7	Methylated spirit	0·83
Marble	2·5-2·8	Olive oil	0·91-0·93
Paraffin	0·87-0·93	Paraffin oil	0·8
Porcelain	2·2-2·4	Turpentine	0·87

2.9. Determination of specific gravity of solids and liquids using a specific gravity bottle. A specific gravity bottle (Fig. 2.11*a*) is a flat-bottomed bulb-like glass bottle with a long, tapering neck. A well-ground solid glass stopper with a narrow bore fits the neck. If the bulb is filled with a liquid and the stopper dropped in place, some liquid comes out through the bore and the bottle contains a fixed volume of the liquid. The internal volume of the bottle is often 20, 25 or 50 cm³.

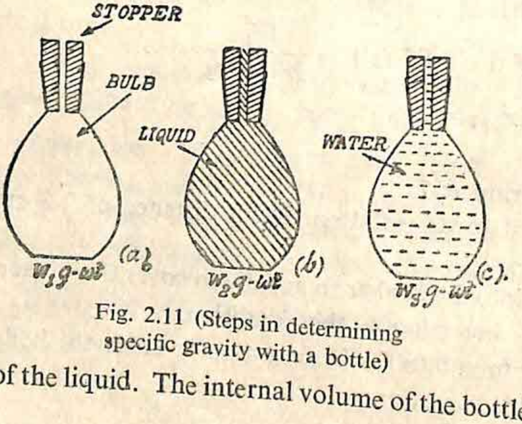

Fig. 2.11 (Steps in determining specific gravity with a bottle)

In a standard bottle the volume and the temperature at which the volume is exact, are marked on the bottle. But a beginner may not get a standard bottle for use because it is costly.

Since volume changes with temperature *a specific gravity bottle* (also called a 'pyknometer') *should always be held by the neck* and never by the bulb.

The bottle is particularly suitable for measuring the specific gravity of liquids and of granular solids. We shall describe three experiments, namely,

(*i*) Determination of sp. gr. of a liquid;

(*ii*) Determination of sp. gr. of a granular solid insoluble in water;

(*iii*) Determination of sp. gr. of a granular solid soluble in water.

2.9.1. Experiment 6

To determine the specific gravity of a liquid using a specific gravity bottle.

Theory. By definition,

Specific gravity of a liquid

$$=\frac{\text{Weight of a given volume of the liquid}}{\text{Weight of an equal volume of water at } 4^\circ\text{C}}$$

Let, the weight of the dry, empty bottle with stopper $= W_1$ g-wt.

the weight of the bottle filled with liquid $= W_2$ g-wt.

the weight of the bottle filled with water $= W_3$ g-wt

$\therefore$ weight of the liquid $=(W_2-W_1)$ g-wt $=W_l$

and weight of the same volume of water $=(W_3-W_1)$ g-wt $=W_w$

Hence Sp. gr. of liquid at room temprature $(t^\circ c)=s'=\frac{W_l}{W_w}=\frac{W_2-W_1}{W_3-W_1}$

$\therefore$ True Sp. gr. $=S'\times S_t$ where S_t is the Sp. gr. of water at room temperature.

Apparatus. Sp. gr. bottle; common balance; weight box; experimental liquid (say methylated spirit, or a water solution); water; blotting paper or old, soft cloth.

[**Directions for the experiment.**

(1) Check if the bottle is clean and dry. (If necessary, it has to be cleaned and dried. For drying, a sand bath or hot air is used. If the bottle is not clean, better ask your teacher how you should clean it. The material that has soiled the bottle may or may not be soluble in water.)

(2) Check if the balance is in order. Then weigh the clean and dry bottle along with the stopper.

(3) Fill the bottle with the experimental liquid, holding it by the neck. Insert the stopper (Fig. 2.11*b*) and wipe off the overflowing liquid with the blotting paper or cloth.

(4) Check if there are any air bubbles in the liquid, particularly below the stopper. These have to be driven out. Those on the inner walls of the bottle may be driven out by shaking the bottle. To remove a bubble below the stopper, completely fill the bottle and have a little liquid above the top. Slide the stopper into this extra liquid and then allow the stopper to drop into place. (Collection of a bubble below the stopper is due to roughness or concavity at the lower end of the stopper. This is faulty construction.)

(5) Weigh the stoppered bottle with the liquid after you have driven out the bubbles and wiped off the overflowing liquid.

(6) Throw out the liquid and wash it several times with water. Then fill it completely with water, drive away bubbles if any, wipe off the overflowing water and weigh.

(7) Leave things as you found them].

Observations

Room temperature (t°c)=...

Sp. gr. of water at t°c=...

No. of obs.	Wt. of the bottle with Stopper W_1 g-wt.	Wt. of the bottle filled with liquid W_2 g-wt.	Wt. of the bottle filled with water W_3 g-wt.	Wt. of the liquid $W_l=W_2-W_1$ g-wt.	Wt. of the Same volume of water $W_w=W_3-W_1$ g-wt.	Sp.gr. (S′) of the liquid	Mean S′
1.							
2.							

Calculations and Result.

Weight of the liquid$(=W_2-W_1)=\ldots-\ldots=$g-wt (W_l)

Weight of some volume of water $(=W_3-W_1)=\ldots$g-wt (W_w)

$\therefore$ Sp. gr. s' of the liquid at room temperature $\left(=\dfrac{W_l}{W_w}\right)=\dfrac{\ldots}{\ldots}=\ldots$

Sp. gr. corrected for temperature $=s'\times s_t=\ldots\times\ldots=\ldots$

Method followed.

(1) The bottle was cleaned and dried.

(2) The empty bottle (with the stopper) was weighed after checking the balance.

(3) The bottle was filled with the experimental liquid, made free of bubbles, stoppered, wiped dry and weighed.

(4) The liquid was thrown out and the bottle washed several times with water. It was then filled with water, made free of bubbles, stoppered, wiped dry and weighed.

(5) Temperature of the water used was noted, and the specific gravity of the water at this temperature was ascertained from the teacher.

Precautions.

(1) No bubbles were allowed to stay in the bottle.

(2) The bottle was always held by the neck.

Oral Questions. (1) How have you cleaned and dried the bottle?

(2) In handling the bottle how should it be held and why?

(3) What is the advantage of having a narrow bore in the stopper?

(4) Why should the stopper be just dropped into place, and not pressed hard?

(5) What is the volume of the liquid in the bottle?

(6) From the weights you have measured do you think that a temperature correction will have an effect on the value of sp. gr. you calculated?

(7) Why should there be no air bubbles in the liquid or water? How did you drive them out?

Answers. (1) Say what you did actually. (Unless you know what made the bottle dirty, you cannot clean it properly. So you have to ask the teacher. Very often light acid and water are used. For cleaning the outside, soap water may be used as grease from the hands might have soiled it. For drying, hot air or sand bath is used.) (2) The bottle should be handled by holding the neck between two fingers, The bottle is to have a fixed volume. Any little change of temperature in the neck has little effect on the volume. But an equal change in the temperature of the bulb has a much larger effect on the volume. (3) For a small change of volume the liquid will come out or the liquid level in the bore will fall. The narrow bore makes it easier to detect any change of temperature. (4) Pressure on the stopper may break the neck of the bottle or change its volume. Or the stopper may stick to the neck. (5) $(W_2 - W_1)$ cm^3. (6) See the 'Remarks' in Experiment 3. Without four significant digits in both the numerator and the denominator for S', temperture correction has no sense, as correction affects the fourth digit. (7) Presence of air bubbles reduces the actual weight of the liquid. This vitates the result. To remove the bubbles on the inner walls, remove the stopper, close the mouth with a finger and shake the bottle. A bubble below the stopper is removed by filling the unstoppered bottle to overflow and then sliding the stopper into place, moving it laterally. (See item 4 under 'Directions for the experiment.')

2.9.2. Experiment 7

To determine the specific gravity of a granular solid, insoluble in water, using a specific gravity bottle.

Theory. If the weight of the granules is W_s g-wt and the weight of an equal volume of water is W_w g-wt, then the specific gravity s' of the solid at room temperature is given by

$$s' = W_s / W_w$$

Let the weight of the empty bottle $= W_1$ g-wt;
weight of the bottle partly filled
with the granules $= W_2$ g-wt;
weight of bottle + granules + water
filling the rest $= W_3$ g-wt;
and weight of bottle completely
filled with water $= W_4$ g-wt.

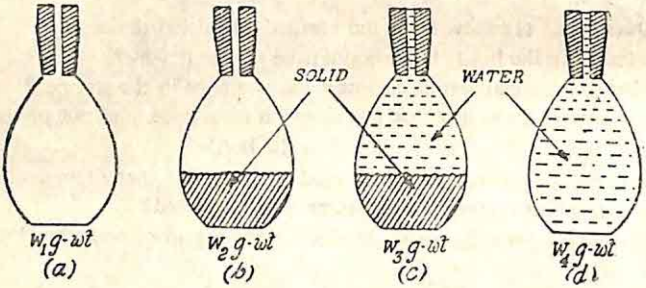

Fig. 2.12 (Successive steps in the experiment)

Then weight of the granules $= W_2 - W_1 = W_s$ g-wt;
weight of water filling the bottle $= (W_4 - W_1)$ g-wt;
weight of water above the granules $= (W_3 - W_2)$ g-wt
Hence weight of water having the same
volume as the granules $= (W_4 - W_1) - (W_3 - W_2)$
$= W_w$ g-wt

The specific gravity at room temperature

$$s' = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} = \frac{W_s}{W_w}$$

True Sp. gr. $= S' \times S_t$ where S_t is the Sp. gr. of water at room temperature (t°c)

Apparatus. Sp. gr. bottle: common balance; weight box; granular solid (say, sand); water: blotting paper or old, soft cloth.

[Directions for the experiment

(1) If necessary, clean and dry the bottle. Check the balance before use and weigh the dry, empty bottle. (Fig. 2.12*a*)

(2) Fill about one-third of the bottle with the granular solid and weigh. (Fig. 2.12*b*)

(3) Fill the rest of the bottle with water. Shake the bottle to drive away the air bubbles entrapped by the granules. Fill the bottle to the brim with water and put in the stopper. Check again for water bubbles, wipe off the overflowing water and weigh. (Fig. 2.12*c*)

(4) Pour out the contents of the bottle and wash the inside several times with water till no granules are left. Then fill the bottle with water, check it for bubbles, stopper it, wipe off the excess water and weigh (Fig. 2.12*d*)]

Observations

Room temperature (t) =...°C

Sp. gr. of water at room tempeature $=S_t=$...

No. of obs.	Wt. of the dry, empty bottle with stopper W_1 g-wt.	Wt. of the bottle partly filled with granules W_2 g-wt.	Wt. of the bottle+ +granules +water above the granules W_3 g-wt.	Wt. of the bottle filled with water W_4 g-wt.	Sp.gr. S′	Mean S′
1.						
2.						

Calculations and Result.

Weight of the granules$=W_2-W_1=$...g-wt (W_s)

Weight of water filling the bottle$=(W_4-W_1)$ g-wt=...g-wt

Weight of water above the granules$=(W_3-W_2)$g-wt=...g-wt

Hence, weight of water having the same volume as that of the granules$=(W_4-W_1)-(W_3-W_2)=$...g-wt(W_w)

∴ The specific gravity at room temperature $s'=\frac{W_s}{W_w}$

$$=\frac{W_2-W_1}{(W_4-W_1)-(W_3-W_2)}=\ldots$$

True Sp. gr.$=S'\times S_t=$...

Method followed.

(1) The clean, dry and empty bottle was weighed after checking the balance.

(2) About one-third of the bottle was filled with the granular solid, and the bottle was weighed with the granules.

(3) The rest of the bottle was filled with water and shaken so as to drive away entrapped air bubbles. It was stoppered, wiped dry with cloth and weighed again.

(4) The bottle was emptied and washed several times with water until no granules were left inside. It was then filled completely with water, stoppered, wiped dry and weighed.

Precautions. No air bubbles were allowed to stay inside the bottle. The bottle was held by the neck between two fingers.

Oral Questions. (1) to (4)—as in the last experiment. (5) What is the volume of the granules? Their weight? Their density? (6) Why should it be particularly necessary to drive away the air bubbles? (7) Do the readings warrant temperature correction?

Answers. (1) to (4)—as in the last experiment. (5) See under 'Calculations' (W_w Cm^3). (W_2-W_1) g-wt ($=W_s$ g-wt). s g/cm^3. (6) The granules form many air pockets. Unless these are removed W_3 will be smaller than the true value because there is some air instead of water in the bottle. This will increase W_w and reduce the value of s. (7) See the answer to Q. 6 of the last experiment.

2.9.3. Experiment 8

To determine the specific gravity of a granular solid, soluble in water, using a specifice gravity bottle.

Theory.

The specific gravity (s_1) of a solid at room temperature is given by

$$s_1=\frac{\text{Weight of a given volume of the solid } (W_s \text{ g-wt})}{\text{Weight of an equal volume of water } (W_w \text{ g-wt})}$$

$$=\frac{\text{Weight of a given vol. of the solid } (W_s \text{ g-wt})}{\text{Weight of an equal vol. of a liquid } (W_l \text{ g-wt})}\times\frac{\text{Weight of same vol. of liquid}}{\text{Weight of same vol. of water}}$$

$=$sp. gr. of the solid relative to the liquid (s_l)$\times$sp. gr. of the liquid relative to water (s').

Let, the weight of the dry empty bottle $=W_1$,
the weight of the bottle+granules $=W_2$,
the weight of the bottle+granules+liquid $=W_3$,
the weight of the bottle filled with liquid $=W_4$
and the weight of the bottle filled with water $=W_5$.

Then weight of the granules $= W_2 - W_1 = W_s$ (Say),

weight of the liquid filling bottle $= W_4 - W_1$,

and weight of the water filling bottle $= W_5 - W_1$.

Hence weight of the liquid having the same volume of the granules $= (W_4 - W_1) - (W_3 - W_2) = W_l$ (say)

$$\therefore \quad S_l = \frac{W_s}{W_l} = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$$

$$\text{and } S' = \frac{W_4 - W_1}{W_5 - W_1}$$

If s_l the sp.gr. of the solid relative to a liquid in which it does not dissolve, and s' the sp.gr. of the liquid relative to water, the product $s_l \times s'$ gives the sp. gr. of the solid at room temperture.

$$\therefore \quad S_1 = S_l \times S' = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} \times \frac{W_4 - W_1}{W_5 - W_1}$$

$\therefore$ True Sp. gr. $= S = S_1 \times S_t$ where S_t is the Sp. gr. of water at room temperture.

Apparatus. Sp. gr. bottle; common balance; weight box; experimental granules (common salt, sugar etc.); a liquid in which the granules do not dissolve (some oil which does not contain any water; turpentine oil may be used with common salt); blotting paper or cloth.

[Directions for the experiment.

(1) to (4)—as in the last experiment (Experiment 7), but read 'the other liquid' for 'water'. (5) Fill the bottle with water and weigh.]

Observations.

Room temperature (t°C) = ...

Sp. gr. of water at t°C (S_t) = ...

No. of obs.	Wt. of the dry empty bottle with stopper W_1 g-wt.	Wt. of the bottle + granules W_2 g-wt	Wt. of the bottle + granules + liquid W_3 g-wt.	Wt. of the bottle filled with liquid W_4 g-wt	Wt. of the bottle filled with water W_5 g-wt	Sp. gr. S_1	Mean S_1
1.							
2.							

Calculations.

$$S_1=\frac{W_2-W_1}{(W_4-W_1)-(W_3-W_2)}\times\frac{W_4-W_1}{W_5-W_1}$$

Result.

Hence the true sp. gr. $=S_1\times S_t=\ldots\times\ldots=\ldots$

Method followed.

(1) to (4)—as in the last experiment, except that you write 'the given liquid. for 'water'. (5) The bottle was filled with water and the weight taken.

Precautions.

As in the last experiment.

Oral questions. (1) to (7)—as in the last experiment. (8) What does the statement 'specific gravity of a substance relative to a liquid' mean? (9) If the sp. gr. of the liquid relative to water is known, how can you calculate the sp. gr. of the substance relative to water? (10) How can you find the sp. gr. of the liquid relative to water using the sp. gr. bottle?

Ans. (1) to (7)—see the corresponding answers in the last experiment.

(8) The ratio of the weight of a given volume of the substance to the weight of an equal volum of the liquid. (9) See 'Theory'. (10) This is experiment 6 (Section 2-9.1).

2-9.4. Hare's apparatus.

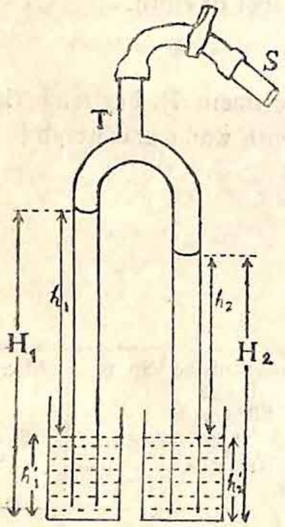

Fig. 2.13

Hare's apparatus is nothing but a inverted U-tube made of glass. At the middle of the U-tube, there is a glass tube T. The tube T and another glass tube S are joined by a rubber tube. With a pinch-cock the rubber tube may be opened or closed. In some instrument a metre scale is fixed behind the U-tube.

The two arms of the U-tube are long. The ends of the tube are dipped into two liquids. By opening the pinch-cock and sucking the air through the tube S, the liquids rise in the tubes. When the pich-cock is closed, the liquid remain in their respective position. The height of the liquid raised depend on the density and the amount of air sucked. Lighter liquid rise to a greater heights. By this instrument we can Compare the densities of the two liquids.

2-9.5. Experiment 9.

To determine the specific gravity of a given liquid by Hare's apparatus.

Theory: In a Hare's tube, if h_1 and h_2 be the heights of the liquid columns of specific gravities S_1 and S_2 respectively, the pressure of the liquid columns are equal on the two liquids *i.e.*

$$h_1S_1g = h_2S_2g$$

$$\text{or, } h_1S_1 = h_2S_2$$

$$\therefore\ S_2 = S_1\frac{h_1}{h_2}$$

If one of the liquids, say S_1, be water, then $S_1=1$, hence, $S_2 = \frac{h_1}{h_2}$. S_2 is the sp.gr. of the liquid at room temperature. The true Sp. gr. of the given liquid $S=S_2 \times S_t$, where S_t is the Sp. gr. of the water at room temperature.

Apparatus: Hare's apparatus, two beakers, Metre Scale, experimental liquid, water.

[**Directions for the experiment:** (1) Place the two beakers below the open end of the U-tube such that the open mouth of the tubes are about 2 cm. above the bottom of the beakers.

(2) Try to keep the whole apparatus vertical as far as possible.

(3) Pour water in one beaker and experimental liquid on the other such that the liquids occupy 3/4th or more of the beakers.

(4) Open the pinch-cock by pressing and suck the air by the tube S, so that the water or the liquid may rise nearly upto the head of the U-tube. Slowly allow the air to enter the tube by opening the pinch-cock. The liquids will come down in both the tubes.

(5) Repeat the process three or four times and you will see that the liquids now move freely up and down but not in jerks.

(6) Now suck again to lift the liquids as far as possible. Take care that the liquids do not reach the bend portion of the tube. Close the rubber tube by the pinch-cock. If the rubber tube in not properly closed, the liquids will come down.

(7) Observe the liquid column for a munite. If it is steady, note the scale readings at the top of the liquid column in the tube and surface of liquid level in the beaker for each liquids, by placing a metre scale by the side of each tube.

(8) Allow the air to enter the tube by slightly opening the pinch-cock. The liquid levels slowly decrease in the tube. When the liquid come down about 2 cm. close the pinch-cock and read the heights again. Repeat the process at least five times by decreasing the height about 2 cm. in each case. Now calculate the specific gravity for each observation.

(9) Plot h_1 along x-axis and h_2 along y-axis and draw a graph. It will be a straight line. Choose a suitable point on the line and find the values of h_1 and h_2. Calculate the Sp. gr. of the liquid.]

Observations:

Room temperature (t°c)=...

Sp. gr. of water at t°c (S_t)=...

No. of obs.	Reading of water level at		Height of the water column $h_1=H_1-h_1'$ cm.	Reading of liquid level at		Height of the liquid column $h_2=H_2-h_2'$. cm.	Sp. gr. of the liquid $S_2=\frac{h_1}{h_2}$	Mean Sp. gr. S_2
	the top of the column H_1cm	the surface of the beaker h_1'cm.		the top of the column H_2cm	the surface of the beaker h_2'cm.			
1.								
2.								
:								
etc.								

Result: Hence the true Sp. gr. of the liquid$=S_2 \times S_t.=$...

Method followed: (1) The two ends of the U-tube were dipped into water and the liquid. The apparatus kept vertical.

(2) The air was sucked. The water and the liquid raised in the respective tube, upto the near of the bend.

(3) The heights of water and liquid were noted by a scale.

(4) By allowing the liquid and water to come down to about 2 cm, the heights were again noted.

(5) The process were repeated and each time the readings were noted.

(6) Sp. gr. of the liquid was calculated from the heights. By drawing a graph, Sp. gr. of the liquid also calculated.

Precautions:

(1) Apparatus should be vertical.

(2) Care should be taken so that liquids do not mix in the tube.

(3) The reading at the bottom of the concave surface should be noted.

(4) In taking readings metre scale should be kept vertical.

Oral Questions and answer

Q. 1. Will the result alter if the lengths were measured in inches?

Ans. No. The Sp. gr. is independent of the unit of length.

Q. 2. What is the harm if the tubes be not of identical cross-section?

Ans. If the cross-sections are large, then it will not affect the result. But if the cross-sections are small then due to capillary action the liquids will rise to a greater heights.

Q. 3. What will be the shape of the liquid meniscus within the tubes?

Ans. The meniscus will be concave for those liquids which wet glass but convex which do not wet glass.

2-10. Simple pendulum.

Introductory. A rigid body which can oscillate about a horizontal axis under the action of gravity is called a *compound pendulum*. Application of mathematics to it is a bit complicated for the beginner. For convenience of applying mathematics to a body oscillating under the action of gravity an imaginary pendulum, called a **simple** or **ideal pendulum,** was conceived. It was defined as "a heavy particle suspended by means of a weightless, inextensible and perfectly flexible string."

It is easy to understand that no simple pendulum can be constructed, for a string with the above qualities and a heavy *particle* are both objects of imagination. A crude model of the ideal pendulum is constructed by suspending a heavy sphere by means of a thin, light, flexible string. The sphere acts as if its mass were at its centre.

Application of simple mathematics to the ideal (or simple) pendulum gives its *periodic time* as,

$$T=2\pi\sqrt{l/g}.$$

l is the length of the pendulum, and is taken as the distance from the point of suspension to the centre of the sphere (the 'bob' of the pendulum). g is the value of the local acceleration due to gravity.

2-10.1. Experiment 10

To determine the acceleration due to gravity using a simple pendulum.

Theory. Let the length of a simple pendulum be l, and g the local value of the acceleration due to gravity. To execute a complete oscillation, such a pendulum will take time

$$T=2\pi\sqrt{l/g}$$

$$\therefore \quad T^2=4\pi^2\frac{l}{g} \text{ and } g = 4\pi^2\frac{l}{T^2}$$

If a graph is drawn with l along the x-axis and T^2 along the y-axis, the graph will be a straight line passing through the origin (the point 0,0). A point suitably chosen on this graph will give the value of l/T^2 ($=x/y$ of the point). This value can be used to calculate g. Alternatively, the mean value of l/T^2 may be taken from a series of observations and substituted in the formula.

Apparatus. A metal sphere (weighing about 100-150 grams) with a suitable arrangement for attaching a string; a piece of light, soft but strong thread over a metre long; clamp on a tall stand; two small, plane pieces of metal or wood; metre scale; stop clock; one or more heavy weights.

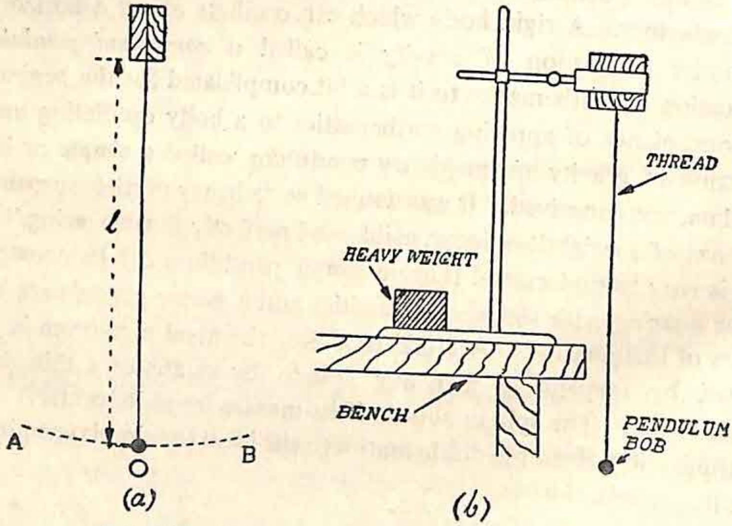

Fig. 2.13. (Properly arranging a simple pendulum.)

[Directions for the experiment. (1) First find the diameter of the bob by a slide callipers [See expt 1(a)].

(2) Tie one end of the tread to the bob. Hold the thread near its other end between the plane plates. Clamp the plates (Fig. 2.13*a*) and fix the clamp to the stand. Arrange the stand as in Fig. 2.13(*b*).

(3) Measure the distance between the point of suspension and the top of the bob with a metre scale. This is l' (say). Add radius of the bob. This is l.

You can measure the distance between the point of suspension and the centre of the bob with a metre Scale. When measured in this simple way there may be an error of 1-2 mm in the measured value of length. But if we use a long pendulum (of length around 100 cm.), the error in the result due to this uncertainty will be about 1 part in 1000. This small error can be tolerated because there are bigger sources of error in the experiment. The error in the length can be reduced by more elaborate means; but we do not consider them worth while. Using slide callipers to measure the diameter of the bob and adding its radius to the length of the string does not improve matters. Whatever the method used for measuring the length, the inability to bring the graduation marks close enough to the end points will always leave an uncertainty in the length. Moreover, variation of pull on the string will cause an unknown change in its length.

(4) Allow the pendulum to oscillate with an amplitude equal to about 1/12 of the length. Be careful that the bob does not execute vibratory motions while oscillating.

In deducing the equation $T=2\pi\sqrt{l/g}$ it was assumed that the amplitude is infinitely small. For angular amplitudes of about 5° the error produced is within limits of tolerance. A 5° angular amplitude corresponds to a linear amplitude of about 1/12 of the length. Larger amplitudes increase T above the value given by theory.

(5) Note the time for 25 oscillations. In Fig. 2.13*a*, a complete oscillation means the journey O→B→O→A→O. Be careful you do not make any mistake in counting. Take the reading at least twice. This will serve as a check on counting, and will also detect any gross error.

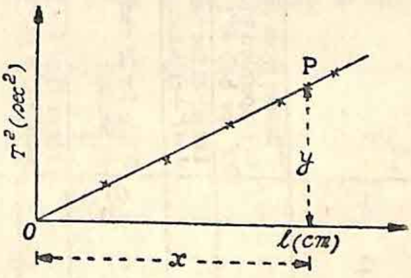

Fig. 2.14 (l-T^2 graph)

(6) Take similar readings for the times of oscillation for at least five different values of l (say, about 120 cm, 110 cm, 100 cm, 90 cm, 80 cm.)

(7) Draw a graph plotting l along the x-axis and T^2 along the y-axis (Fig. 2.14). It should be a straight line and pass through the origin ($x=0$, $y=0$). Draw the

best straight line through the origin which passes through most of the points. (See Section 1-8 for instructions on drawing graphs.) Take a suitable point P on the graph; it should lie at a corner of a small square. Find the ratio x/y for the point. This is the value of l/T^2, which is a constant. Substitute this value in the formula for g. Take $\pi=3.14$ and $\pi^2=9.86$]

Observations

(*i*) To find the radius of the bob by a slide-callipers:
Value of one smallest scale division (s)=... cm
...(n) vernier divisions=...($n-1$) main Scale divisions.

$\therefore$ Vernier constant $(v.c)=\frac{1}{n}\times s$ cm.

No. of obs.	Main Scale reading in cm. (M)	Vernier reading (V)	Value of Vernier reading in cm. V×v.c	Diameter in cm d=M+V×v.c	Mean diameter in cm.	Mean radius r in cm.
1. (*a*)						
(*b*)						
2. (*a*)						
(*b*)						
3. (*a*)						
(*b*)						

(*ii*) To find the time period of the pendulum:

No. of obs.	Distance from the point of suspension to the top of the bob (l') in cm.	Length of the pendulum $l=(l'+r)$ in cm.	Time for 25 oscillations in Seconds	Mean Time for 25 oscillations in Seconds	Periodic time (T) in seconds	T^2 in S^2	l/T^2 cm/s²	Mean l/T^2 in cm/s²	$g=4\pi\frac{l}{T^2}$ in cm/s².
1.			(*i*) (*ii*)						
2.			(*i*) (*ii*)						
⋮			...						
etc.			etc.						

Calculations

(*i*) From Graph: The l-T^2 graph is drawn. It passes through the origin. From the point P on it, it is found that for $l=$...cm, $T^2=$... s^2. Therefore

$$g=4\pi^2\frac{l}{T_2}=4\times 9{\cdot}86\times\frac{\ldots\text{cm}}{\ldots\text{s}^2}=\ldots\text{cm/s}^2$$

(*ii*) Calculated value of $g=4\pi^2\frac{l}{T^2}=4\times 9{\cdot}86\times\frac{\ldots\text{cm}}{\ldots\text{s}^2}=\ldots\text{cm}/s^2$

[If you do not draw the graph, take the mean value of l/T^2 and use this value in the formula. Even if you draw the graph, use also the mean value of l/T^2 to calculate g. If the graph is not properly drawn, the mean value of l/T^2 may give you a better value of g.]

Method followed.

(1) The radius of the bob was calculated by a slide-callipers.

(2) A tall stand was placed near an edge of the working table. A heavy weight was placed on its base so that it would not topple. The pendulum (of length about 120 cm) was held in the clamp between two plane pieces of wood and made to hang outside the table. The distance between the point of suspension and the top of the bob was measured.

(2) With the pendulum at rest, a mark was made on the side of the table against the pendulum thread. This helped in noting complete oscillations. Time was measured from the moment the thread crossed this mark.

(3) The pendulum bob was pulled to one side by about 1/12th the length of the pendulum and allowed to oscillate. Care was taken to see that the bob did not vibrate about its point of attachment to the string.

(4) Time for 25 oscillations was measured twice with the help of a stop clock.

(5) The length of the pendulum was reduced by about 10 cm., the length measured and the time for 25 oscillations noted as before.

(6) This was done for altogether five different values of the length.

(7) The l-T^2 graph was drawn.

Precautions.

(1) Wind should not be allowed to disturb the oscillations.

(2) The bob must not vibrate while oscillating.

(3) The linear amplitude should not exceed one-twelfth the length of the pendulum.

(4) T had to be carefully measured.

[Reasons for the precautions.

(1) Disturbed oscillations will not give the correct value of T.

(2) Such oscillations are also disturbed oscillations.

(3) See the matter in small type under item (4) of 'Directions for the experiment'.

(4) A 1% error in the value of T affects the result by 2% because g involves T^2. An error of 1% in l affects g by 1%.]

Directions for drawing the graph.

If l varies between 60 cm and 120 cm, T^2 will vary roughly between 2·40 s^2 and 4·80 s^2. Since the graph passes through the origin it is desirable to have the origin ($x=0$, $y=0$) on the graph.

So we shall have to plot 0 to 120 along the x-axis and 0 to 4·80 along the y-axis. Graph papers can be had in many sizes. If a graph paper has 200 small divisions along one axis and 250 divisions along the other, then since T^2 is to have the greater accuracy, we can use the 250 division side for plotting T^2. To get a convenient unit along this axis (the y-axis) 1 small division may represent 0·02s^2. Then 4·80 s^2 will require 240 divisions.

For 120 cm of length we have 200 divisions. So we may make 1 small division correspond to 1 cm instead of taking a fraction of a small division to do so. Such fractional divisions as units are inconvenient. 1, 2, 4 or 5 divisions are good values as units.

Remarks. Since the correct experimental result in this experiment is already known, it offers a scope for malpractice. Some teachers and examiners lay too much emphasis on the so-called correctness of the experimental result. This attitude should be given up where beginners are concerned. It is this attitude which encourages malparactice by the student. An experiment crudely done with crude apparatus can never be expected to yield a near-correct result. If it does, it is an accident. One error must have cancelled another by chance. Honest, careful and methodical work should be encouraged, whatever the result.

Using a long pendulum with a small amplitude, and taking sufficient care in measuring T, one may expect the result to lie within 1% of the true value. Such a result should be considered 'good'.

Oral questions. (1) What is a simple pendulum? (2) What is meant by acceleration due to gravity? (3) How would you realize a simple pendulum in practice? (4) What is the length of the pendulum so constructed? Why? (5) Between l and T, which should be measured with greater care and why? (6) What graphs connecting l and T will be straight lines? (7) How can you get the required result from the graph? (8) To get good results, what values of l and amplitude would you prefer? (9) What is the harm if the pendulum is short and its amplitude large?

Answers. For (1), (3) and (4), see Section 2-10. (2) The acceleration with which a body moves while falling towards the earth freely under the action of the earth's pull. (5) In measuring T. See item (4) under 'reasons for the precautions'. (6) The l-T^2 and $\sqrt{l}$-T graphs. (7) See item (6) under 'Directions for the experiment'. (8) Large values of l. Amplitudes less than one twelfth the length. See items (3) and (4) under 'Directions for this experiment'. (9) Both increase the experimental error.

2-11. Experiment 11.

To verify Boyle's law.

Theory. Boyle's law states that for a fixed mass of gas at constant temperature, the volume is inversely proportional to the pressure, or that the product $P \times V$ is constant. This can be verified by measuring the volumes at different pressures and noting if the product remains constant so long as the temperature or the mass of gas does not change.

[Graphical verification of the law is also possible. P vs. $1/V$ graph, V vs. $1/P$ graph, or $\log P$ vs. $\log V$ graph will be a straight line if the law is true.]

Apparatus. Boyle's law apparatus.

Descritpion of the apparatus. The essential parts of the apparatus are shown in Fig. 2.15. T is a glass tube of uniform bore closed at the top and contains a fixed amount of dry air. The other end of the

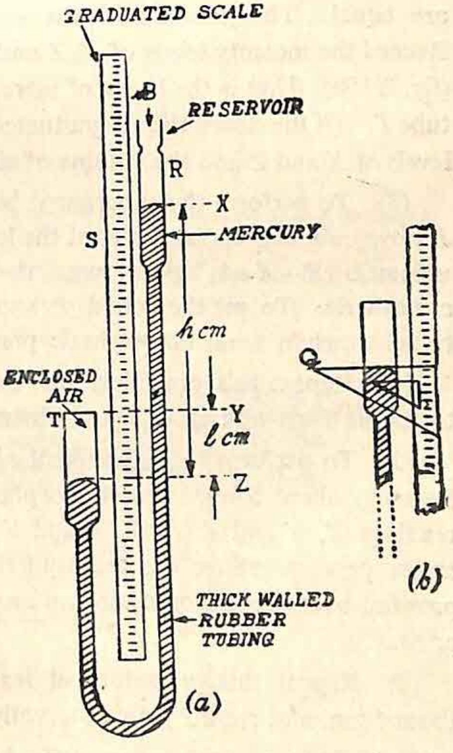

Fig. 2.15 (*a*) Essential parts of Boyle's law apparatus; *b* How to take readings.)

tube is connected to a thick rubber tube containing mercury. The other end of the rubber tube is connected to a mercury reservior R. The air is contained between the upper end of T and the head of mercury in T. The tube T and the reservoir R lie on two sides of a vertical scale graduated in millimetres. They can be raised or lowered vertically and kept fixed in position anywhere within their limits of movement.

In some apparatus, there is a eudiometer tube in place of the tube T, with its zero mark of volume at the upper end. From the graduations of the (eudiometer) tube, one can read off the volume of the enclosed air directly.

[Directions for the experiment.

(1) At the start of the experiment note the barometric height and room temperature.

(2) Raise or lower T or R so that the mercury levels in T and R are equal. The pressure in the closed tube is now atmospheric. Record the mercury levels of *X*, *Z* and *Y* with the help of a set-square (fig. 2.15b). That is the levels of mercury heads in *R*, *T* and top of the tube *T*. (If the closed tube is graduated in cm^3, then record the mercury levels of *X* and *Z* and the volume of air in the closed tube *T*.

(3) To perform the experiment below atmospheric pressure lower *R* slowly about 5 cm. and record the levels of *X*, *Y* and *Z* (or *X*, *Z* and volume). $Z-X=h_1$ gives you the reduced pressure below the atmosheric. To get the actual pressure over the enclosed air you are to substract h_1 from atmospheric pressure.

(4) Repeat this procedure at least 3 times each time lower *R* to about 5 cm and record you observation.

(5) To perform the experiment above atmospheric pressure raise R slowly about 5 cm. above atmospheric pressure reading and record readings *X*, *Y* and *Z* (or *X*, *Z* and Volume). $X-Z=h_2$ gives you the excess pressure above the atmospheric pressure. To get the actual pressure over the enclosed air you are to add h_2 with the atmospheric pressue.

(6) Repeat this procedure at least 3 times each time raise R to about 5 cm. and record your observations.

(7) Note again the barometic height and room temperature. Calculate the value of $p \times l$ (or $p \times v$) in each case.

(8) Draw a graph plotting p along x-axis and corresponding l (or v) along y-axis. It should be a rectangular hyperabola. This also verifies Boyle's law.]

Observations:

(*i*) To record the barometric height and room temperature:

Smallest division of the main scale=...mm.

...vernier divisions =... main Scale divisions.

one vernier division=... main Scale division.

∴ Vernier constant (v.c.)=... mm=... cm.

Observations at the	Main Scale reading in cm (M)	Value of vernier reading (v) in cm. ($V=v\times$v.c)	Atmospheric pressure ($H=M+V$) in cm. of Hg.	Mean H in cm of Hg.	Room temperature in °C.	Mean Room temperature in °C
Start of the experiment						
end of the experiment						

(*ii*) To record length (or volume) and pressure of the enclosed gas: When the tube is not graduated

Observation at pressure	No. of obs.	Readings in cm. of mercury levels in		Readings in cm. of the top of the closed tube (T)	Length of the enclosed air in cm. $l=(T-C)$	Reduce or excess pressure $h=(C\sim O)$	Pressure of the enclosed air in cm. of Hg. $P=H\pm h$	Value of $P\times l$
		Closed tube (C)	Open tube (O)					
Atmospheric	1.							
Below atmospheric	2. 3. 4.							
Above atmospheric	5. 6. 7.							

When the tube is graduated

Observations at pressure	No. of obs.	Readings in cm. of mercury levels in		Volume of the enclosed air in cm.^{3}	Reduce or excess pressure $h=C\sim O$ cm.	Pressure of the enclosed air in cm. of Hg. $P=H\pm h$	Value of $P\times V$
		Closed tube (C)	Open tube (O)				
Atmospheric	1.						
Below atmospheric	2.						
	3.						
	4.						
Above atmospheric	5.						
	6.						
	7.						

Conclusion. Since $P\times l$ (or $P\times V$) is practically constant, it may be concluded that Boyle's law is true.

[The differences in the product are due to experimental error. At the most, only three of the digits of the product are significant. The third is uncertain. So keep only three digits in the product $P\times l$ (or $P\times V$)].

Method followed: (1) At the start of the experiment the barometer reading and room temperature were noted.

(2) The mercury levels in closed and open tube brought to the same level and the positions of the mercury levels in closed and open tubes and also the top of the closed tube (or volume) were noted. The pressure in now atmospheric.

(3) The mercury reservoir was lowered by about 5 cm and the readings of the levels of mercury in two tubes and the top of the closed tube (or volume) were noted.

(4) This process were repeated 3 times and in each case the readings were noted.

(5) The mercury reservoir was raised above atmospheric pressure by about 5 cm. and the correspondig reading of the mercury levels and top of the tube (or volume) were noted. This process also repeated 3 times and the reading were noted as before.

(6) The barometer reading and room temperature were again noted.

(7) A graph was drawn plotting P along x-axis and corresponding v or l along y-axis. The nature of the graph is a rectangular hyperbola.

Precautions: (1) Raise or lower the mercury reservoir slowly and wait a few minutes before taking reading. Sudden changes of volume change its temperature. Time must therefore be allowed so that air in closed tube regains its original temperature (the temperature of the room).

(2) The enclosed gas should be dry, because moist air do not obey Boyle's law.

Remarks. The P *vs.* $1/V$ (or P vs. $1/l$) graph will be a straight line if Boyle's law is true. The graph should pass through the origin (0, 0). See if your graph does so. It will be a test of the quality of your work.

The same applies to the V vs $1/P$ graph. You may also try the graph log P vs. log V (or log l). This will also be a straight line, but will not pass through the origin.

Oral questions (1) What is Boyle's law? (2) How will the product PV change if the temperature or the mass of gas is increased? (3) Why have you worked with the length l of the air column instead of its volume V? (4) When is the pressure in the air tube greater than the atmospheric pressure? When is it less? (5) Does P mean the pressure *exerted by* the gas, or the pressure *applied to* the gas? (6) Is there any harm if the air contains moisture? (7) Why is it necessary to raise or lower the vessels slowly, and wait a few minutes before taking the readings? (8) Is Boyle's law applicable only to air?

Answers (1) See 'Theory.' (2) The product will increase in both cases. The product is proportional to the 'Absolute temprature' of the gas, and to its mass. (3) Since the cross section a of the tube is constant $V=la$. So V is proportional to l. (4) When mercury level in the reservoir is at a greater height than that in the air tube, the pressure on the air is greater than the atmospheric pressure. If the level in R is lower than that in T, the air pressure is less than atmospheric. According to hydrostatics, the pressure at the same horizontal level in two vessels connected by a liquid, is the same. (5) The pressure exerted by a confined volume of air is equal to the pressure exerted on it. Ordinarily, air pressure would mean the pressure exerted by the air. (6) Water vapour does not obey Boyle's law, particularly if it is near saturation. Moist air will be more compressed than dry air when the pressure is increased. (7) See under 'Precautions'. (8) No, the law is applicable to all gases.

2.12. Young's modulus

Introductory. If the longitudinal pull on a wire is increased, its length increases. Until this pull (or tension) exceeds a certain limit, the increase in length is proportional to the applied force. This limit is called the **elastic limit.** It depends on the nature of the material of of the wire and its cross section.

The increase in length (l' cm) that occurs when the pull is a load of W g-wt is called the *longitudinal deformation*. When l' cm is divided by the original length (l cm) of the wire we get the increase in length per centimetre length of the wire. This quantity, l' cm$/l$ cm$=l'/l$, is called the *longitudinal strain*. It is a pure number and does not require any unit to express it.

Let the cross section of the wire be S cm^2, and the acceleration due to gravity g cm/s^2. When the load W g-wt is applied, a force of Wg dynes acts perpendicular to the section S. So the longitudinal pull (or tension) per cm^2 of the wire is Wg dynes$/S$ cm^2. This is called the **longitudinal stress.**

The ratio of longitudinal stress to the longitudinal strain is called **Young's modulus** of the material of the wire.

$$\text{Young's modulus } E=\frac{\text{Longitudinal stress } (Wg \text{ dyn}/S \text{ cm}^2)}{\text{Longitudinal strain } (l' \text{ cm}/l \text{ cm})}$$

$$=\frac{Wg}{S}\cdot\frac{l}{l'}\,\frac{\text{dyn}}{\text{cm}^2}.$$

2.12.1. Experiment 12

To determine Young's modulus of a given wire and to verify Hooke's law.

Theory. Let a vertical wire of length l cm and cross section S cm^2 be weighted at the bottom by a load of W g-wt. If it then increases in length by l' cm, then its longitudinal strain is l' cm$/l$ cm. The longitudinal stress is W g-wt$/S$ cm$^2=(Wg/S)$ dyn/cm^2, g being the acceleration due to gravity. Young's modulus E of the material of the wire is defined by the relation

$$E=\frac{\text{longitudinal stress}}{\text{longitudinal strain}}=\frac{Wg}{S}\left(\frac{\text{dyn}}{\text{cm}^2}\right)\Big/\frac{l'\text{cm}}{l\text{ cm}}=\frac{Wg}{S}\cdot\frac{l}{l'}\,\frac{\text{dyn}}{\text{cm}^2}.$$

Hooke's law states that when a body is deformed, the deformation produced will be proportional to the deforming force, unless the deformation exceeds elastic limit. If a graph is drawn plotting W along x-axis and l' along y-axis and if the graph is a straight line passing through the origin then the deformation (l') will be proportional to the deforming force (W) which varifies Hooke's law.

Apparatus. Young's modulus apparatus; a set of equal weights ($\frac{1}{2}$kg or 1 kg each), preferably slotted; a long light straight rod or stick; metre scale; screw gauge.

Descritption of apparatus.

(There are various designs of apparatus for measuring Young's modulus. Since the elongation (increase in length) is small, it is measured with a fine vernier scale or a micrometer screw. The design differs according as a vernier or micrometer is used. Even for verniers, there are different designs. We describe below a relatively common form of vernier apparatus.)

Fig. 2.16 represents an apparatus for measurng Young's modulus in which a fine vernier scale is used for measuring the elongation. The experimental wire A is suspended from the ceiling. The vernier scale V is attached at its lower end. Two other wires (in some cases, one) of the same material as A are suspended parallel to A from the same support. They carry a metal plate D on which the main scale is marked. A heavy, hollow cylinder S is fixed to the lower ends of the wires. The cylinder keeps the wires B, C taut. The vernier can slide along the main scale through vertical grooves in D. At the end of A there is a hook (H) which supports the slotted, stretching loads.

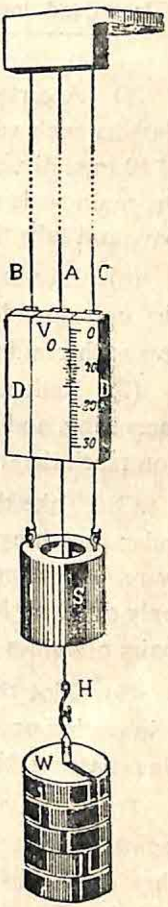

Fig. 2.16
(Young's modulus
apparatus)

[Directions for the experiment.

(1) To keep the experimental wire (A) free of kinks, place a load of 1 or 2 kg on the stand for slotted weights attached to the wire. Treat it as a 'dead load' and don't take it into consideration in your calculation of stretching loads. (Note it as 'dead load'.)

(2) Measure the length *l* cm of the experimental wire from its point of suspension to the point of attachment to the vernier. Do it with the long rod or stick and the metre scale.

(3) Take six sets of readings of the diameter *d* of the wire at six different places (taking two readings in perpendicular directions at each place). Calculate the cross section of the wire from the mean value of *d*.

$$(S=\tfrac{1}{4}\pi d^2=0{\cdot}785d^2)$$

(4) *Ascertain from your teacher-in-charge the breaking stress and calculate the breaking load (=breaking stress×area of cross section) of* the wire (that is, the minimum *load at which the wire will snap).* Calulate the limiting load by dividing the breaking load by two. Don't apply to A a load more than this value (for you may then exceed the elastic limit and cause a permanent elogation of the wire).

Breaking stresses (kg-wt/mm^2)

Brass	35-55	Steel (ordinary)	112
Copper (annealed)	28-31	,, (tempered)	155
Iron (hard drawn)	54-62	,, (pianoforte)	186-233

(5) Ascertain the vernier constant. (You may require a reading glass as such verniers are very fine. You may have a correspondence of 19 m.s. div. to 20 vern. div. or of 24 to 25 or even 49 to 50.). Note the main scale and vernier readings with only 'dead load' on the pan, and take this reading as the reading for zero load.

(6) Increase the stretching loads by $\frac{1}{2}$ or 1 kg at a time and note the corresponding main scale and vernier readings. Take at least five such readings.

(7) Reduce the stretching loads by the same amount as while increasing, and read the main scale and vernier each time. Do so until you reach the dead load. (Don't remove the dead load.)

(8) Take the mean value of the two readings you got for a particular stretching load W while the loads were increasing and while they were decreasing. The difference between this reading and that with only the dead load, is the elongation l' for load W. Thus you get five pairs of values of W, l',

(9) Plot the W, l' points with W (load) along the x-axis and l' (elongation or extension) along the y-axis. They should lie on a straight line passing through the origin ($W=0, l'=0$).

(10) Draw the straight line graph and choose on it a remote point P which passes through the corner of a small square. Determine the values of W and l' for this point, and use them in your formula for E. Take $g=980$ cm/s^2. Since the value of d may not contain more than two significant digits, your final result will have uncertainty in the second significant digit.]

Observations and Calculations.

Dead load $=$...*kg-wt.*

Length l of the wire $=$...cm.

Pitch of the screw gauge$=$...*mm; number of division on* circular scale$=$...

Least count $=$...mm

Zero error of the gauge$=$...(Nil, or...mm to be added/subtracted)

Diameter of the wire (use table as in Sec. 2-3)

Mean value of apparent diameter $=$...mm.

Actual diameter $=$apparent diam$+$zero error $=$...mm$+$...mm$=$...mm $=$...cm(d)

Cross section S of the wire $=\frac{1}{4}\pi d^2=0.785\ d^2=$...cm^2

Breaking Stress $=$... Kg-wt/cm^2 (Supplied)

Breaking load $=$Breaking Stress$\times$cross-section of the wire $=$...$\times\frac{1}{4}\pi d^2=$...Kg-wt.

Limiting load $=$Breaking load/2$=$... kg-wt.

Load-elongation table

No. of obs.	Additional load over dead load. kg-wt	Readings when the load increasing: Main Scale in cm.	increasing: Value of Vernier in cm.	increasing: Total in cm.	decreasing: Main Scale in cm.	decreasing: Value of Vernier in cm.	decreasing: Total in cm.	Mean in cm.	Elongation (l') of the wire in cm.
1.	0								
2.	1								
3.	2							...(a)	...($a-a$)
⋮	⋮							...(b)	...($b-a$)
etc.	⋮							...(c)	...($c-a$)

Result. The **W**-l' graph is drawn, taking l' in cm (Fig. 2.17). From the point P on the graph, we get that for **W**$=$...kg-wt.,

$l'=$...cm. Taking $g=980$ cm/s^2 and putting these values in the equation for E we get

$$E=\frac{\cdots\text{kg-wt}(W)}{\cdots\text{cm}^2(S)}\cdot\frac{\cdots\text{cm}(l)}{\ldots\text{cm}(l')}$$

$$=\frac{W\times1000\times980\text{ dyn}}{S\text{ cm}^2}\cdot\frac{l\text{ cm}}{l'\text{ cm}}$$

$$=\ldots\text{dyn/cm}^2$$

[Check by using the mean values of W and l' in the formula]

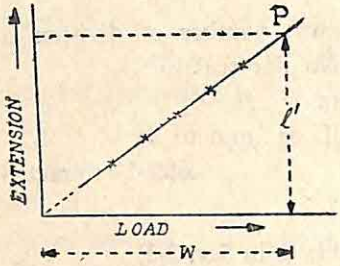

Fig. 2.17 (W-l' graph)

Verification of Hooke's law.

As the stress (W) versus strain (l') graph is a straight line passing through the origin, it is concluded that the strain is proportional to the stress. Hence Hooke's law is verified.

Note. If the graph was found to curve beyond a certain value of W, we would conclude that up to a certain value of the stress, the strain is proportional to it. The point from where the line begins to curve marks the *elastic limit*.

Method followed.

(1) A dead load of 2 kg was placed on the pan attached to the experimental wire to keep it taut. It was not included in calculating the stretching load.

(2) The length and cross section of the wire were determined.

(3) The breaking load was ascertained by knowing the breaking stress. I did not apply more than half this load as it might exceed the elastic limit.

(4) The vernier constant was determined. The main scale and vernier readings with only the dead load were noted. It is the reading for $W=0$.

(5) The load on the pan was increased by 1 kg at a time. I went up to...kg-wt. The corresponding main scale and vernier readings were taken each time.

(6) The loads were then diminished by the same amount at a time, and the corresponding readings taken, till I reached the dead load.

(7) The elongation (l') for a load W was calculated from the mean readings for that load and the initial reading.

(8) The W-l' graph was drawn. It was a straight line through the origin. A point P on the corner of a square through which the graph passed was chosen and the values of W and l' corresponding to it were used for calculating E.

Precaution. (1) The experimental wire should be free from kinks. A dead load of...kg-wt was placed on the pan to keep the wire taut. (2) The total load (including the dead load) must not be greater than half the breaking load of the wire. A greater load may cause it to exceed the elastic limit.

Oral questions. (1) What is Young's modulus? On what does it depend? What are its units in the cgs system? (2) What is elastic limit? (3) Explain the terms 'longitudinal stress' and 'longitudinal strain'. What are their units? (4) Why is it necessary to have another wire of the same material as the experimental one? Should they have the same diameter? (5) What is 'dead load'? Why is it used? (6) Why is the vernier read twice, once while the load is increasing and again when it is decreasing? (7) Explain how you drew the graph and used it. (8) What is Hooke's law? (9) What do the terms 'Stress' and 'Strain' mean?

Answers (1) See 'Theory'. E depends on the material, and to some extent on the temperature. It is independent of the diameter or length of the wire. In dynes/cm^2 units. (2) If a body is deformed by applying a force, ordinarily the body regains its original size and shape when the deforming force is removed. But if the applied force exceeds a limit, the body may be left with a permanent change of shape or size. This limit is called the 'elastic limit'. (3) See Section 2-12. Stress is expressed in dynes/cm^2 units. Strain is a pure number and does not require any unit. (4) If the room temperature changes, the length of the experimental wire will also change. The second wire is used for correcting for this change. The change in length is the same in both wires due to the temperature. So the vernier readings are not affected. The wires need not have the same diameter, as temperature affects them equally. (5) The 'dead load' keeps the experimental wire free of kinks. If there is a kink (a little bending), straightening of the wire will lower its end without any change of actual length. Presence of a kink will thus vitiate results. (6) To reduce the experimental error. Sometimes the vernier may stick and give a false value. (7) See items (8) and (9) under 'Directions for the experiment'. The O, O point should be on the graph. (8) See theory. (9) Stress meant the load per unit area, and strain meant the elongation per unit length.

Young's modulus (dyn/cm^2)

Aluminium	7.05×10^{11}	Steel	$19.5\text{-}20.6 \times 10^{11}$
Brass	$9.7\text{-}10.2 \times 10^{11}$	Plastics	$0.14\text{-}1.1 \times 10^{11}$
Copper	$10.5\text{-}13.0 \times 10^{11}$	Rubber (soft vulcanized)	$0.15\text{-}0.5 \times 10^{8}$

2-12.2. To determine Young's modulus using a micrometer screw. Young's modulus apparatus using a micrometer screw is known as *Searle's apparatus* (for Young's modulus). Its construction is shown in Fig. 2.18.

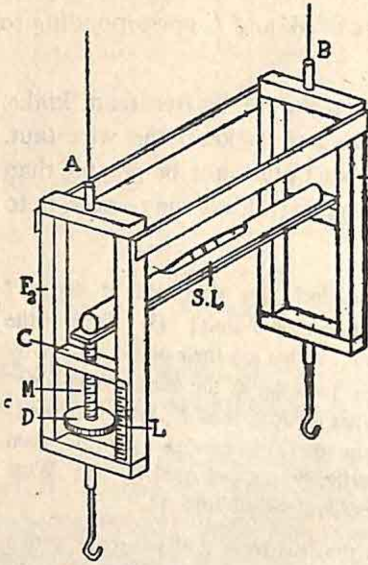

Fig. 2.18 (Searle's apparatus)

The comparison wire B terminates in a frame F_1 which supports the dead load. The experimental wire A is attached to a similar frame F_2. The two frames are connected by cross pieces so that they are unable to move laterally relative to each other. But F_2 may be depressed when loads are hung from its lower end.

A spirit level* S.L. is supported at one end on a rigid cross bar of F_1. Its other end rests on the point of a micrometer screw M. M can move vertically through a rigid cross bar. The disk D attached to the other end of M is divided into 50 or 100 circular divisions. As D is turned, M moves up or down. The extent of vertical motion of M is read off from the linear scale L and the circular scale on D. (Compare the action of a screw gauge or spherometer screw.)

The wire A will also have a dead load keeping it free of kinks. The spirit level is adjusted to be horizontal by turning D. This gives the initial reading. The load on A is increased by steps of 1 or $\frac{1}{2}$ kg at a time, the spirit level adjusted, and the readings taken. The same is done when the loads are decreasing. The procedure is thus the same as with the vernier apparatus, except that the elongation is measured by the micrometer screw, the spirit level serving as reference.

Beginners will find the use of Searle's apparatus too complicated for them. *Its use is not recommended at this stage.* But if any institution has only this apparatus and no simpler one, students should be given adequate help.

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*A spirit level is a glass tube containing alcohol and a bubble of air. The tube has the form of an arc of a circle. It is mounted in a metal tube with a plane flat bottom. When the bottom is horizontal, the air bubble is at the top centre of the glass tube, which is convex upward. A line on the glass tube marks this central position. If the centre of the bubble is on this line, the flat bottom is horizontal.

CHAPTER 3

LIGHT

3-1. Introductory remarks on 'LIGHT' experiments.

When light falls on a surface, a part of it is reflected, a part is transmitted and the rest is absorbed. The nature of the surface determines what the different fractions will be. A well-polished metal plate, a glass mirror with a silver backing, white paper or cloth reflects most of the incident light. Surfaces like those of a glass plate, glass prism or lens etc, transmit most of the incident light. A black surface absorbs most of the incident light.

Light moves in a straight line in a homogeneous medium. The path along which light moves in going from one point to another is called a *ray*. A *pencil of rays* is a collection of rays of small cross-section. A collection of pencils of rays is a *beam* or *bundle of rays*. A *parallel pencil*, *beam*, or *bundle* of rays is one in which all the rays are parallel. If all the rays move towards the same point it is a *convergent* beam or pencil. If all rays of a pencil or beam come from the same point, it is a *divergent* one.

Ray tracing. In tracing rays we take the help of pins. (A ray-box can also be used; but very few of our laboratories have it. So we shall not discuss it.) Suppose a pin P_1 (Fig. 3.1, top) is fixed on a table in open light. We can see it by the rays reflected from its sides. Fix another pin P_2 in such a way that you cannot see P_1 (Fig. 3.1, bottom). It would mean that the ray by which you were seeing P_1 has been stopped by P_2. So the line P_1 P_2 represents the ray coming from P_1 to P_2.

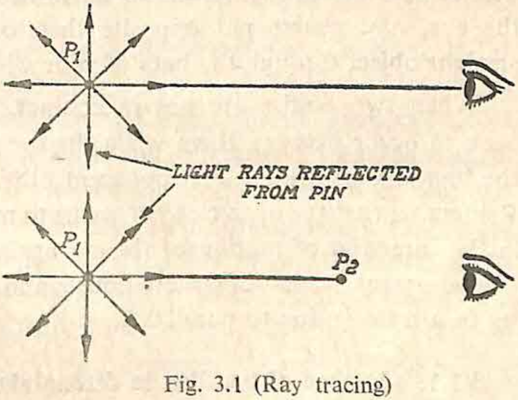

Fig. 3.1 (Ray tracing)

All experiments with the help of pins are best done near an open window. You get enough light. It is convenient to *have the pins painted white or yellow. They can then be seen more clearly.* Thin pins are better for ray tracing than thick pins.

Parallax. In optical experiments, the position of an image is often determined by noting its 'parallax' with a pin (or some other body). Let us see what parallax is and how it can be used for determing a position.

In Fig. 3.2, P_1 and P_2 are two pins some distance apart. When you look along the line P_1P_2 with one eye, you cannot say which is closer and which is farther away. This happens when your eye is at E; P_1, P_2 are along your line of sight. Suppose you move your eye at right angles to the line of sight to the position E_1. From here you can distinguish the positions of P_1 and P_2. The more distant pin P_2 seems to move in the same direction in which you have moved your eye. The nearer pin P_1 moves in the opposite direction. When the eye is moved in the opposite direction to E_2, things are reversed. The remote pin always seems to move in the direction of motion of the eye, and nearer pin opposite thereto. (Look at some remote straight object through the bars of your window, and check it.)

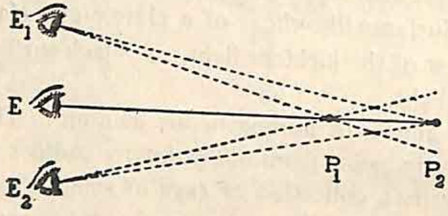

Fig. 3.2 (Parallax)

When two bodies are not in contact. a relative displacement is seen to occur between them when the eye is moved at right angles to the line joining them. This apparent displacement is called **parallax.** Remember that the nearer object seems to move in a direction opposite to the direction of motion of the eye against the remote background. (The apparent motion of remote houses and trees when you are travelling in a train is due to parallax.)

3-1.1. Method of parallax in determining the position of an image. Suppose a lens has formed an image of a pin at P_2 (Fig. 3.3). To find its exact position we take another pin P_2. Let the second pin be at P_1'. Move your eye perpendicular to the line P_1' P_2. P_1'

will be seen to move opposite to the motion of the eye against the background. P_2 will seem to move in the direction of motion of the eye relative to P_1'. This means P_1' is nearer to the eye than P_2. If the pin P_1' be placed at P_1'', and you move your eye as before, the opposite will seem to happen. This will tell you that P_1'' is too far away from you than P_2. You can accordingly adjust the position of P_1 to bring it into conicidence with P_2, as shown at P_1''' (Fig. 3.3). When P_1 is at position P_1''', there will be no relative motion between P_1 and the image P_2 when you move your eye. This will tell you that the two pins P_1 and P_2 are at the same place. Thus, by removing parallax you find the position of the image.

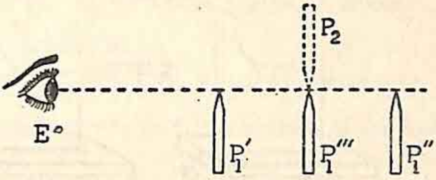

Fig. 3.3 (Determining position by the method of parallax.)

3-1.2. Experiments with lens and mirror. In experiments with a lens or mirror it is necessary to measure the distances of the object and the image from the lens or mirror. If the object is a point object, the distances can be measured accurately. You may get a point object in either of two ways. It may be the point of a pin or it may be the junction point of two fine wires placed as a cross(×). It is easier to get a pin and use it. So we shall take the point of a pin as our point object in lens or mirror experiments.

Optical bench. In measuring the object distance u and the image distance v, *optical benches* are often used. Such benches vary widely in construction. But every bench has at least three stands, with holders —one each for the object, the lens and the search pin to locate the image. The holders may be raised or lowered so that the centre of the lens, the point object and the point of the search pin for the image may lie on the same horizontal line parallel to the length of the bench. The stands can slide along a metre scale fixed to the bench. There is a mark on each stand which tells you the position of the lens or either of the pins it holds. From the distance between these marks you can get u or v.

Figures 3.4(*a*) and (*b*) show two such stands of very simple construction. These are of wood. The vertical board has a V cut. The sides of the V may be grooved along the middle. The lens or mirror sits in this groove (Fig. 3.4*a*). Two inverted pins are fixed vertically in the groove with plasticine, glue or wax. Care is taken so that the centre of the lens and the points of the pins are at the same height. The mark M (Fig. 3.4*b*) gives the position of the pin on the stand.

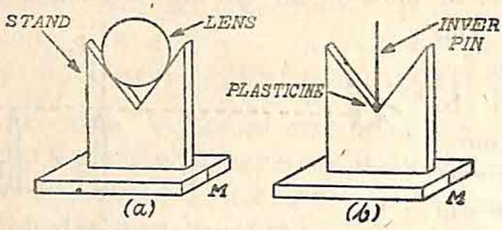

Fig. 3.4 (Simple stands for optical experiments).

A polished wooden board with a metre scale fixed on it (Fig. 3.5) may serve as a simple optical bench. The three stands described above can slide alongside the metre scale. (Any carpenter can make such a stand for you. You need not wait for a sophisticated stand from instrument manufacturers.) Even without the board you can use the stands. Place them on the table alongside a metre scale. This will serve as an optical bench good enough for your purpose.

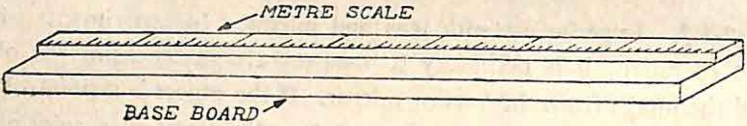

Fig. 3.5 (Optical bench without stand)

Get familiar with the optical bench you may have in your laboratory. Note the adjustments the stands and the holders may have. The adjustment essential for your work is that the centre of the lens and the points of the object pin and search pin should lie on a horizontal line parallel to the length of the bench. The stands should slide along the bench without lateral motion.

If the marks (M) on the stands do not give the correct positions of the lens (mirror) or the pins, corrections for getting u and v from the apparent readings will be necessary. Ascertain from your teacher if any such correction will be necessary.

3-2.1. Experiment 13

To verify the laws of reflection of light.

Theory. The laws of reflection of light are

(*i*) The angle of incidence (i) is equal to the angle of reflection (r).

(*ii*) The incident ray, the reflected ray and the normal at the point of incidence lie in the same plane.

Apparatus. A thin glass mirror mounted on one side of a plane rectangular piece of wood (the base of the wood and the plane of the mirror should be at right angles); four long pins (we may call them 'optical pins'); drawing paper; drawing board; four drawing pins; a protractor (preferably transparent) for measuring angles; a sharp pencil.

[Directions for the experiment.

(1) Fix the drawing paper on the drawing board. Draw a straight line M_1M_2 (Fig. 3.6) near the middle of the paper. Place the mirror vertically with its reflecting plane on this line. (The reflecting plane of a glass mirror is its back side, which has the silver coating.)

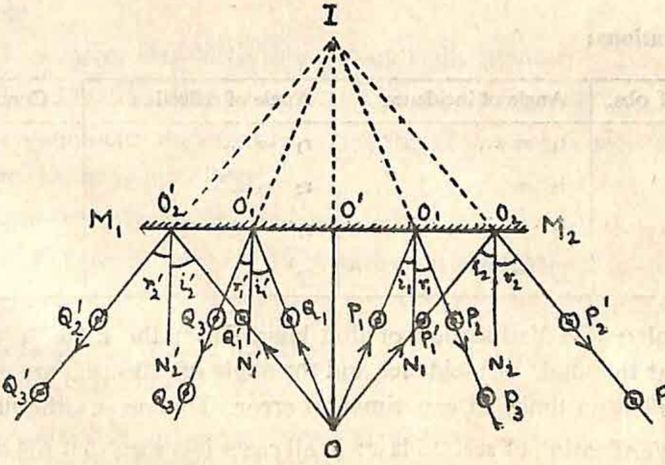

Fig. 3.6 (To verify the laws of reflection)

(2) Fix the pins O and P_1 on your right-side to determine the direction of the incident ray. So place the pin P_2 that it is seen in a line with the images of O and P_1 formed in the mirror. Place the

fourth pin P_3 also on that line. The images of O, P and the pins P_2, P_3 will all appear to be on the same straight line. OP_1 gives you the direction of the incident ray. P_2P_3 gives you the direction of the reflected ray.

(It will be good to have O about 10 cm from the mirror, and P_1 about 2 cm from the mirror. Similarly for P_2 and P_3).

(3) Do not move the mirror and the pin O. Withdraw pins P_1, P_2, P_3 and draw small circles with pin-prick points as centres.

(4) Fix the pin P_1' with an increasing angle of incidence on the same side of P_1 and place the two pins P_2', P_3' and make similar construction as in (2)

(5) On your left side make similar constructions with pins Q_1, Q_2, Q_3 and Q_1', Q_2', Q_3.

(6) Remove the mirror and the pin O. Join OP_1, OP_1', OQ_1, OQ_1' and produce them to meet M_1M_2 at O_1, O_2, O_1', O_2'. Similarly join P_2P_3, $P_2'P_3'$, Q_2Q_3, $Q_2'Q_3'$ and produce them to meet M_1M_2. If the constructions has been good they will meet at O_1, O_2, O_1', O_2'.

(7) With the help of protractor draw lines O_1N_1, O_2N_2, $O_1'N_1'$, $O_2'N_2'$ perpendiculars to M_1M_2 at O_1, O_2, O_1', O_2' and measure the angles of incidence i_1, i_2, i_1', i_2' and angles of reflection r_1, r_2, r_1', r_2'.]

Observations:

No. of obs.	Angle of incidence	Angle of reflection	Conclusion.
1.	i_1 = ...	r_1 = ...	
2.	i_2 = ...	r_2 = ...	
3.	i_1' = ...	r_1' = ...	
4.	i_2' = ...	r_2' = ...	

Results: (*i*) Verification of first law: From the table it can be seen that the angle of incidence and the angle of reflection are equal in all cases within limits of experimental error. This proves the first law.

(*ii*) Verification of second law: In all cases it is seen that the incident rays, the reflected rays and the normals at the points of incidence are all lie in the plane of the paper. This proves the second law.

Method followed.

(1) I fixed the drawing paper flat on the drawing board. Then

I drew a line (M_1M_2) near the middle of the paper and parallel to the edge. The reflecting surface (the back surface) of the mirror was placed on this line.

(2) I fixed two pins O and P_1 in front of the mirror to define an incident ray. A third pin P_2 was so fixed that the images of O and P_1 in the mirror and the pin P_2 appeared to lie on the same line. A fourth pin P_3 was also fixed on the same straight line. OP_1 determines the incident ray and P_2P_3 the reflected ray.

(3) Without moving the mirror pins P_1, P_2, P_3 were withdrawn and small circles were drawn with pin-prick points as centres.

(4) Another similar construction was done on the same side of P_1 and two others on the other side of O.

(5) The mirror was removed. OP_1, OP_1', OQ_1 OQ_1' were joined and produced to meet the line M_1M_2 at O_1, O_2, O_1', O_2'. Also P_2P_3, $P_2'P_3'$, Q_2Q_3 $Q_2'Q_3'$ were joined and these line passed through O_1, O_2, O_1', O_2' respectively. O_1N_1, O_2N_2, $O_1'N_1'$, $O_2'N_2'$ were drawn perpendiculars to M_1M_2 at O_1, O_2, O_1', O_2'.

(6) I measured angles of incidence and angles of reflection by a protractor.

Precautions:

(1) The mirror should be thin and optically plane.

(2) The direction of the ray should be shown by an arrow head.

(3) To eliminate the error in measuring angles the angles of incidence should be made large.

(4) The pins should be fixed vertically.

(5) The mirror should not be disturbed in the least while the rays are being drawn.

Oral questions. (1) What is reflection?

(2) What is a 'ray' of light?

(3) Explain the terms:

(*i*) incident ray, (*ii*) reflected ray, (*iii*) point of incidence, (*iv*) normal at the point of incidence, (*v*) plane of incidence.

(4) How can the direction of a ray be shown? Have you shown them in your figures?

(5) Should an optical pin be thick or thin? Why?

(6) What are the laws of reflection?

(7) Would you prefer a thick glass mirror or a thin one? Why?

Answers: (1) When light is incident on a surface, a part of it is returned into the first medium. This phenomenon is called reflection. (2) Light moving from one point to another is a ray of light. The term is also applied to the path along which the light mvoes. (3) The ray that falls on a surface is an incident ray. The ray that is returned from the surface is a reflected ray. The point where the incident ray strikes the surface is the point of incidence. The perpendicular drawn on the reflecting surface at the point of incidence is the normal at the point of incidence. The plane which contains the incident ray and the corresponding reflected ray is the plane of incidence. (Here the plane of the paper.) (4) The direction of the ray is shown by an arrow head. (5) Thin. The straight line joining the centres of the holes that the pins make in the paper marks the ray. So, the thinner the pins the lesser the error. (6) See 'Theory'. (7) Thin. The reflecting surface is the back surface. If the glass is thick, refraction will bring the back surface nearer to the front surface. A polished metal mirror will be better than a glass mirror, because its front surface is the reflecting surface.

3-2.2 Experiment 14

To show that in case of reflection on a plane mirror the object distance, is equal to the image distance.

Theory. The virtual image is formed by a plane mirror at the same distance behind the mirror as the object in front of it, i.e., object distance (u)=image distance (v).

Apparatus. Same as previous experiment.

[Directions for the experiment: (1) to (6) Same as previous experiment.

(7) Produce (Fig. 3.6) the reflected rays P_2P_3, $P_2'P_3'$, Q_2Q_3 and $Q_2'Q_3'$ behind the line M_1M_2. They will meet at I. So I is the virtual image of O. Join OI. It will cut the line M_1M_2 at O′ perpendicularly. Measure three times the distances OO′ and IO′ with a scale. They will be equal]

Observations.

No. of obs.	Readings in cm the position of the			Object distance u (00′) in cm.	Image distance v (0′1) in cm	Conclusion
	object (0)	mirror (0′)	Image (I)			
1.						
2.						
3.						

Results. From the table it is seen that the object distance is equal to the image distance within limits of experimental error.

Method followed. (1) to (5) Same as previous experiment.

(6) The reflected rays P_2P_3, $P_2'P_3'$, Q_2Q_3, $Q_2'Q_3'$ produced behind the line M_1M_2. They meet at the point *I*. *OI* was joined. It cut the line M_1M_2 at O′. The object distance OO′ and image distance IO′ were measured three times with a seale.

Precaution. Same as previous experiment.

Oral Questions (1) Define image. (2) How many types of images are there? (3) What type of image is formed by a plane mirror?

Ans. (1) When the rays of light from a point source after reflection or refraction converge at a point or appear to diverge from a point, the second point is called the image of the first. (2) Two types—virtual and real (3) Virtual. For other questions and answers see expt. No. 13.

3-3. Experiment 15

To verify the laws of refraction of light.

Theory. The laws of refraction of light are

(*i*) The incident ray, the refracted ray and the normal at the point of incidence, all lie in the same plane.

(*ii*) If *i* be the angle of incidence and *r* the angle of refraction, then for refraction of light of a given colour from one given medium to another given medium, the ratio $\sin i/\sin r$ is a constant independent of *i*. This constant is known as the refractive index (*u*) of the second medium with respect to first. The second law is also known as Snell's law.

Apparatus. A rectangular slab of glass; four optical pins; drawing paper, board and pins; protractor for measuring angle.

[Directions for the experiment.

(1) Fix the drawing paper to the drawing board with four drawing pins.

(2) Place the slab of glass near the middle of the paper (Fig. 3.7). Draw its boundary with a sharp pencil. Be careful that the slab is not disturbed during the work.

(3) Fix two optical pins *O* and P_1 on one side of the slab to mark

the incident ray. Look through the other side of the slab and fix the pins P_2 and P_3 so that the images of O, P_1, appear on the same straight line as P_2, P_3. OP gives you the direction of the incident ray and P_2P_3 gives you the direction of the emergent ray.

(4) Do not move the slab and the pin O. Withdraw pins P_1, P_2, P_3 and draw small circles with pin-prick points as centres.

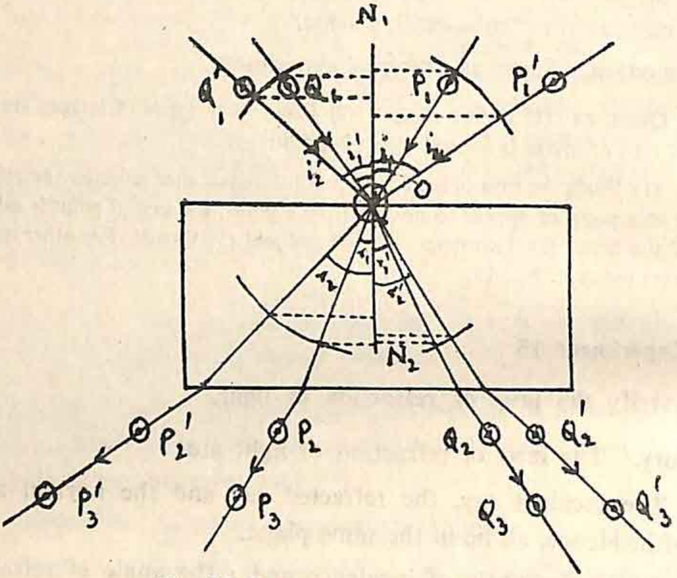

Fig. 3.7 To verify the laws of refraction

(5) Fix the pin P_1' with an increasing angle of incidence on the same side of P_1 and place the two pins P_2', P_3' and make similar construction as in (3).

(6) On the other side make similar constructions with pins Q_1, Q_2, Q_3 and Q_1', Q_2', Q_3'.

(7) Remove the slab and the pin O. Join OP_1, OP_1', OQ_1, OQ_1', P_2P_3, $P_2'P_3'$, Q_2Q_3 and $Q_2'Q_3'$. Draw lines where the emergent rays meet the outline of the slab from O. These lines gives you the refracted rays.

(8) With the help of a protractor draw N_1ON_2, perpendicular at the point O. Measure the angle of incidence i_1, i_2, i_1', i_2' and angle of refraction r_1, r_2, r_1', r_2'.

(9) Draw a circle with O as centre and radius less than the thickness

of the slab. Draw perpendiculars on N_1ON_2 from the points where the incident and refracted rays cut the circumference of the circle. Measure these perpendiculars.

(If the slab was undisturbed during any of these operations, and your drawing has been accurate, you will find that the incident rays and emergent rays (OP_1 and P_2P_3 etc) are parallel. Check this. This is *important*)].

Observations.

Table I

No. of obs.	Angle of incidence (i)	Angle of refraction (r)	Sin i	Sin r	$\mu = \frac{\text{Sin i}}{\text{Sin r}}$	Remarks
1.						Within experimental error the ratio Sin i / Sin r is constant. This verifies 2nd law of refraction.
2.						
3.						
4.						

Table II

No. of obs.	Perpendicular distances in air (d) (cm)	Perpendicular distances in the medium(d′) (cm)	$\mu = \frac{d}{d'}$	Remarks
1.				
2.				
3.				
4.				

Results. (*i*) Verification of first law: In all cases the incident ray, the refracted ray and the normal at the point of incidence are all lie in the same plane—here the plane of the paper. This proves the first law.

(*ii*) Verification of second law: From the table I and II it is seen that Sin *i*/Sin *r* remain constant within experimental error. Thus Snell's law is verified.

Method followed.

(1) The drawing paper was fixed to the drawing board. The rectangular slab of glass was placed on the paper and its outline was drawn with a sharp pencil.

(2) Two pins O and P_1 were fixed on one side of the slab to mark the incident ray. The line OP_1 marks the *incident ray*.

(3) Looking through the opposite side of the slab a third pin P_2 was so fixed that the images of O, P_1 and the pin P_2 appeared to lie on the same straight line. A fourth pin P_3 was fixed on the same line about 8-10 cm away from P_2. $P_2 P_3$ marks the *emergent ray*.

(4) Without moving the slab and the pin O, pins P_1, P_2 and P_3 were withdrawn and small circles were drawn with pin-prick points as centres.

(5) Four such construction were made, two on the left side and two on the right side.

(6) The Slab and the pin O were withdrawn. Incident rays, emergent rays and refracted rays were drawn. A perpendicular N_1ON_2 was drawn at the point O.

(7) The angles of incidence and the angles of refraction were measured by a protractor.

(8) A circle was drawn with O as centre and radius less than the thickness of the slab. Perpendiculars were drawn on N_1ON_2 from the points where the circle meet the incident and refracted rays. The perpendiculars were measured with a scale.

Precaution. (1) The glass slab must not be disturbed in the least while the rays are being drawn

(2) The opposite faces of the slab should be parallel.

(3) The direction of the ray should be shown by arrow head.

(4) To eliminate the error in measuring angles, the angles of inci-incidence should be made large.

(5) The pins should be fixed vertically.

Oral questions. (1) What are the laws of refraction?

(2) What is Snell's law?

(3) What is refractive index?

(4) Does your experiment give the value of any refractive index?

(5) What are the media to which this μ refers?

(6) What is the value of refractive index for refraction from glass to air?

(7) What will be the angles of incidence and refraction in your drawing if refraction was considered to take place from glass to air?

(8) How is μ related to the velocities of light in the two media?

Answers: (1) and (2)—See 'Theory'. (3) The ratio sin i/sin r. (4) and (5), yes; it gives the refractive index for refraction from air to glass. (6) The reciprocal of μ that I have got here. (7) Then r will be the angle of incidence and i the angle of refraction into air. (8) Refractive index of the second medium relative to the first= Velocity in the first medium ÷ velocity in the second medium.

Table of Sines of angles

$\theta°$	sin θ	$\theta°$	sin θ	$\theta°$	sin θ
14	0.242	35	0.574	56	0.829
15	0.259	36	0.588	57	0.839
16	0.276	37	0.602	58	0.848
17	0.292	38	0.616	59	0.857
18	0.309	39	0.629	60	0.866
19	0.326	40	0.643	61	0.875
20	0.342	41	0.656	62	0.883
21	0.358	42	0.669	63	0.891
22	0.375	43	0.682	64	0.899
23	0.391	44	0.695	65	0.906
24	0.407	45	0.707	66	0.914
25	0.423	46	0.719	67	0.921
26	0.438	47	0.731	68	0.927
27	0.454	48	0.743	69	0.934
28	0.470	49	0.755	70	0.940
29	0.485	50	0.766	71	0.946
30	0.500	51	0.777	72	0.951
31	0.515	52	0.788	73	0.956
32	0.530	53	0.799	74	0.961
33	0.545	54	0.809	75	0.966
34	0.559	55	0.819	76	0.970

For fractional angles add the proportionate difference.

Example: $\sin 37{\cdot}5° = \sin 37° + (\sin 38° - \sin 37°) \times 0{\cdot}5$
$= 0{\cdot}602 + (0{\cdot}616 - 0{\cdot}602) \times 0{\cdot}5 = 0{\cdot}609.$

3-4.1. Spherical Mirror : A portion of a sphere having reflecting surface is called a spherical mirror. The centre of the sphere of which the mirror is a part is called 'centre of curvature' and its radius 'radius of curvature' of the mirror. The middle point of the mirror is called pole of the mirror. The line joining the centre of curvature and the pole is called the axis of the mirror.

A spherical mirror may be 'concave' or 'convex'. If the centre of curvature lies on the same side of the reflecting surface, the mirror is called concave and if it lies on the other side the mirror is called convex. We shall confine ourselves to concave mirror only.

When a beam of rays, parallel to the axis, is incident on a concave mirror, the rays after reflection converge to a point on the axis of the mirror. This point is called the focus of the mirror. The distance along the axis from the pole of the mirror to its focus, is called the focal length of the mirror. The plane through the focus which passes perpendicular to the axis of a mirror is called its focal plane.

A point object placed on the axis of a concave mirror at a distance from it greater than its focal length, forms a point image on the axis on the same side of the mirror. The object distance (u), the image distance (v), radius of curvature (r) and focal length (f) are related by the relation $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}=\frac{2}{r}$. To make it clear on which side of the mirror the object, the image, the radius of curvature and focus lies, the nature of the image (real or virtual), the symbols u, v, r and f are endowed with positive (+) or negative(–) sign according to some accepted convention. There are different conventions in use.

3-4.2. Experiment 16

To find the focal length of a concave mirror by the method of coincidence (with or without a optical bench)

Theory. The relation between the object distance u, the image distance v, the radius of curvature r and the focal length f of a concave mirror, with pole as origin, is given by

$$\frac{1}{v}+\frac{1}{u}=\frac{2}{r}=\frac{1}{f},$$

when $u=r$, i.e., when the object is placed at the centre of curvature, the above formula reduces to

$$v=r=2f,$$

which means the image is also formed at the centre of curvature. So focal length of the mirror can be calculated from the relation $f=\frac{r}{2}$.

Apparatus. Concave mirror with stand, Object pin with adjustable stand, metre scale (or optical bench).

[Directions for the experiment :

(We shall describe what to do if there is no optical bench. These instructions will also tell you how to use the optical bench.)

(1) Mount the object pin vertically on the stand and place it near the concave mirror. Adjust its height so that the tip of the pin passes very close to the axis of the mirror.

(2) Move away the object pin from the concave mirror until you see a real and inverted image of the pin through the mirror. Adjust the object pin and its image in the same vertical line and coincide their tips by moving the object pin up or down.

(3) Move the object pin slowly until there is exact coincidence between the object pin and its image i.e. there is no parallax (see section 3-1.1) between the two. (See fig. 3.8)

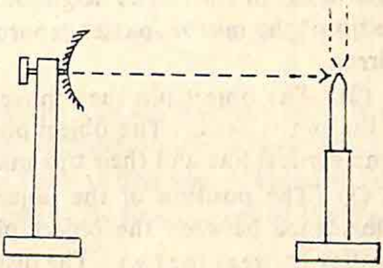

Fig. 3.8

(4) Measure the distance between the pole of the mirror and the tip of the object pin by a metre Scale (If you use a optical bench then note the psitions of the mirror and the object pin from the scale fixed by the side of the optical bench. The difference of these positions give you the value of *r*.)

(5) Disturb the set up and repeat independently the same procedure several times to get the positional coincidence between the object pin and its image. Each time measure the distance between the mirror and the object pin (or note the positions of the mirror and object pin). Calculate mean of these values. Half of this mean value give you the focal length of the concave mirror.]

Observations.

Without optical bench.

No. of obs.	Distance between the object pin and the pole of the concave mirror in cm. (r)	Mean value of r in cm.	Focal length of the mirror f=r/2 in cm.
1. 2. 3. : etc.			

With optical bench

No. of obs.	Position of the mirror in cm. (M)	Position of the object pin in cm. (O)	Radius of curvature of the mirror $r=M\sim 0$ in cm.	Mean value of r in cm	Focal length of the mirror f=r/2 in cm.
1. 2. 3. : etc.					

Results. Hence the focal length of the given concave mirror= ...cm.

Method followed: (1) The object pin and the concave mirror were mounted vertically on the stand and the object pin was placed very close to the mirror. The height of the object pin was so adjusted that the tip of the mirror passes approximately through the axis of the mirror.

(2) The object pin then moved away until a real inverted image of the pin is seen. The object pin and its image were brought in the same vertical line and their tips made coincident.

(3) The position of the object pin was adjusted till there is exact coincidence between the object pin and its image i.e. there was no parallax between the two. The distance between the pole of the mirror and the object pin was measured by a metre scale (The positions of the mirror and the object pin were noted).

(4) The set up was disturbed and the same operation were repeated several times. From these observations the focal length of the mirror was calculated.

Precautions.

(1) Positional coincidence of the object pin and its image should be carefully ascertained by avoiding parallax.

(2) The object pin should be vertical.

(3) The distance between the pole of the mirror and the object pin should be measured horizontally.

(4) The aperture of the mirror must be small.

Oral questions. (1) Can a concave mirror produce a virtual image? If it can, then how can you locate the position of the image?

(2) You are given two concave mirror of same focal lengths but of different aperture. Which one you prefer and why?

(3) How can you identify a concave mirror?

(4) Define the terms: centre of curvature, radius of curvature, pole, axis, focus and focal length of a mirror.

Ans. (1) The image is virtual behind the mirror when the object is placed in between the pole of the mirror and the focus. The position of the image can be located by 'no parallax' method with a search pin behind the mirror. (2) The mirror of smaller aperture, because if the aperture is large then due to spherical aberration and distortion it will be difficult to locate the exact position of the image. (3) An object placed very close to the mirror will produce an erect, virtual and magnified image. (4) See 3-3.1

3-5. Spherical lens

A transparent medium bounded by two spherical surfaces is a 'spherical lens'. The line joining the centres of the two spherical surfaces is called the *axis* of the lens. Though lenses may have other shapes we shall deal only with spherical lenses.

A spherical lens may be 'convex' or 'concave'. A *convex lens* is thicker in the middle and thinner at the edges. A concave lens is thinner in the middle and thicker at the edges. We shall confine ourselves to convex lenses only.

When a beam of rays, parallel to the axis, is incident on a lens, the rays converge to a point on the axis after refraction at both surfaces of the lens. This point is called the *focus* of the lens. The distance along the axis from the centre of the lens to its focus, is called the *focal length* of the lens.

A convex lens whose refractive index is greater than that of the surrounding medium, increases the convergence of a beam of rays incident on it. Such a lens is also called a *convergent lens.* Since we generally use glass lenses in air, they are all convergent in the given situation. For this reason, the terms 'convex' lens and 'convergent' lens are sometimes used synonymously. But the difference may be remembered. For similar reasons, a concave lens is also called a divergent lens.

The plane through the focus which passes perpendicular to the axis of a lens is called its *focal plane*.

A point object placed on the axis of a lens at a distance from it greater than its focal length, forms a point image on the axis on the other side of the lens. The object distance (u), image distance (v), and focal length (f) are related quantities. To make it clear on which side of the lens the object, the image or the focus lies, the symbols u, v, f are endowed with the positive ($+$) or the negative ($-$) sign according to some accepted convention. There are different conventions in use. According to one the formula connecting u, v, f is $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$. According to another it is $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$.

3-5.1. Experiment : 17

To determine the focal length of a given convex lens by u-v method (Conjugate foci method).

Theory. For a convex lens the relation between the object distance

u, the image distance v and the focal length f is given by

$$\frac{1}{f}=\frac{1}{v}-\frac{1}{u}.$$

For real image the image distance v is negative. So the above formula can be written as

$$\frac{1}{f}=-\frac{1}{v}-\frac{1}{u}=-\frac{u+v}{uv}$$

$$\text{or,}\quad f=-\frac{uv}{u+v}.$$

knowing the values of u and v, f can be determined.

Apparatus. Experimental lens; lens holder on a stand; two optical pins mounted on stands; metre scale (or optical bench).

[Instead of pins an illuminated cross may serve as object and a white screen to determine the position of the image.]

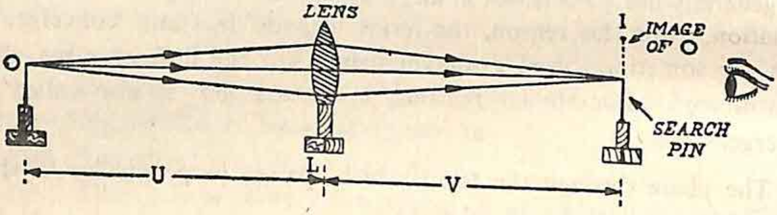

Fig. 3.9

[Directions for the experiment.

(We shall describe what to do if there is no optical bench. These instructions will also tell you how to use the optical bench.)

(1) Take the lens near a window and form with it the image of a bright, distant object (20-30 m away) on a piece of white paper. Measure the distance between the lens and the image. This gives you and approximate value of the focal length. It is of advantage to have this knowledge.

(2) Mount the lens, the object pin (or illuminated cross) and the search pin (or white screen) on a stand. See if the sharp ends of the pins (or cross and centre of the screen) lie at about the same height as the centre of the lens. It not, adjust them to be so as far as you can. The pins (or cross and screen) must be vertical. The mark on the stand should give the correct position of the pins (or cross and screen).

(3) Place one of the pins (or the cross) at a distance of about

2*f* from the lens and on its axis. Look (or place the screen) for the image on the other side of the lens at about the same distance. (your eyes will have to be about 25 cm. farther away to see the image.) Adjust the pins in the same vertical line and coincide their tips by moving the pins up or down. Arrange the search pin so that there is no parallax (See. 3-1.1) between the image pin and the tip of the search pin (or arrange the screen so that the image of the illuminated cross received on the screen as sharp as possible). Place a metre scale by the side of the pins (or illumininated object, screen) and lens and note the position of the pins (or illuminated object, screen) and lens from the scale. Keeping the object pin (or cross) in the same position disturb the search pin (or screen) and adjust independently the same procedure two times more. The mean of these three readings will give you the position of the image.

(4) Vary the position of the object pin (or cross) between $1\frac{1}{2}f$ and 3*f*. For each position of the object, find the image position three times as above and measure the corresponding values of *u* and *v*.

(5) Do so for at least five values of *u*. Then calculate the value of *f*.

(6) Draw a graph plotting *u* along *x*-axis and *v* along *y*-axis, The graph will be a rectangular hyperbola. Take a suitable point on the graph and also find the value of *f*.]

Observations and calculations.

With or without optical bench and pins.

No. of obs	Position in cm of the				Object distance in cm (u) (L∼O)	Image distance in cm (v) (L∼S)	focal length $f=\frac{uv}{u+v}$ in cm.	Mean focal length in cm.
	object pin (O)	lens (L)	Search pin (S)	Mean (S)				
1.	....	....	(*i*) (*ii*) (*iii*)	....	....	....	....	
2.	....	....	(*i*) (*ii*) (*iii*)	....	....	....	....	....
etc.								

With illuminated object and screen

No. of obs	Position in cm. of the				Object distance in cm 'u'	Image distance in cm 'v'	focal length $f=-\frac{uv}{u+v}$	Mean focal length in cm
	illuminated object (O)	lens (L)	Screen (S)	Mean (S)	(L∼O)	(L∼S)		
1.	....	..	(*i*) (*ii*) (*iii*)	....				
2.								
⋮								
etc.								

Result. The mean value of the focal length of the given lens= ···cm.

Method followed. (1) An approximate value of the focal length was obtained by forming the image of a distant object.

(2) The sharp ends of the pins (or illuminated object and centre of the screen) and centre of the lens were adjusted to be at the same height as for as possible.

(3) The object pin (or illuminated object) was placed on the axis of the lens at different distances between $1\frac{1}{2}f$ and $3f$ from the lens and the corresponding positions of the image were derermined with the search pin (or Screen) by the method of parallax (or so that the image of the illuminated object received on the screen as sharp as possible. Corresponding values of u and v were measured. For one position of the object three independent image positions were determined and the mean value was taken.

(4) Five sets of readings were taken in this way. f was calculated from each pair of u-v values and the mean was taken as the focal length of the lens.

(5) A graph was plotted taking the values of u along x-axis and v along y-axis. The nature of the graph was a rectangular hyperbola. From the graph f also calculated.

Precautions. (1) To find the exact position of the image, parallax must be avoided.

(2) The minimum error in measuring f will be when $u=v$ i.e. when the object is placed at $2f$. So the object should be placed around $2f$.

(3) The aperture of the lens should be small, otherwise due to spherical aberration the exact position of the image cannot be determined.

Oral questions. (1) What do you understand by 'focal length' and 'axis' of a lens?

(2) What is a 'thin' lens?

(3) From which point are u, v and f measured in a thin lens?

(4) What is a 'point object'?

(5) Explain 'parallax' and how you use it to locate the position of an image.

(6) Are the words 'convex lens' and 'convergent lens' synonymous?

(7) Can a convergent lens always form a real image of a real object?

(8) Distinguish between 'real' and 'virtual' images.

Ans. (1) See Sec. 3.3. (2) A 'thin' lens is one the thickness of which can be ignored compared with its focal length. (3) From the midpoint of the lens. But if ignoring the thickness is permissible, the distance may be measured from the nearer pole of the lens. (4) An object whose dimensions (that is, length breadth and thickness) are negligible compared with its distance from a lens. (5) See Section 3-1.1 (Fig. 3.3). (6) See Sec. 3-3. (7) Not if the object lies between the focus and the lens. (8) If a divergent pencil from a point object is brought to a point focus after reflection or refraction, the image is 'real'. If after reflection or refraction the rays from a point object *appear* to come from another point, the latter point is the 'virtual' image of the first. A real image can be received on a screen, but not a virtual image. The image seen in a plane mirror is virtual.

CHAPTER
4

HEAT

4-1. Introductory remarks on 'HEAT' experiments.

When a body gains or loses heat energy, one of the following effects is observed:

(1) A change in temperature,

(2) A change of dimensions (length, area, volume) and pressure;

(3) A change of state (from solid to liquid, etc. and vice versa).

In the experiments we shall have to do, it will be necessary for us to measure a mass, a quantity of heat and a change in temperature. Heat is a measurable quantity and has to be expressed in proper units.

Measurement of temperature. Temperature is measured by using a thermometer. Though there are many kinds of thermometers, we shall use only the mercury-in-glass theremometer. Temperature will be expressed in celsius (the old 'centigrade') degrees (°C). The temperature of melting ice is taken as 0°C and the normal boiling point of water as 100°C. One-hundredth of this difference of temperature is a celsius degree. To differentiate between a temperature reading 1°C and a difference of temperature of one celsius degree, some authors write the difference as '1C deg' or '1C°'. But the practice is not uniform. So when you see 10°C, you are to understand from the context whether it is the thermometer reading or a temperature difference.

Precaution in the use of a thermometer.

(*a*) Choose a thermometer of suitable range. In reading it look perpendicularly to the scale. Otherwise there will be parallax error.

(*b*) A thermometer is a fragile (=easily breakable) instrument. Handle it with care, particularly when stirring water.

(*c*) Try to read a thermometer up to one-tenth of a division (0·1°) by eye estimation. The greatest error in a 'Heat' experiment is caused by the smallness of temperature difference. This often makes the result uncertain in the second significant digit.

(*d*) In experiments on calorimetry, temperatures must be recorded quickly. But a thermometer takes some time to reach the proper temperature. Time must be allowed for this. (In reading the doctor's thermometer you allow it enough time to reach the temperature of the patient.)

(*e*) Keep the thermometer in its case when not in use.

4-1.1. Unit of heat and some important thermal quantities. The unit of heat in the cgs system is the **calorie** (symbol, cal). The amount of heat energy required to raise the temperature of one gram of pure water from 14·5°C to 16·5°C is called a *calorie*. It is necessary to mention the initial temperature because water does not take the same amount of heat for a one degree rise at all points of the temperature scale. For ordinary purposes, this difference can be ignored. So we shall consider that one gram of water has taken t calories of heat when its temperature rise is t celsius degrees. (This is like taking the mass of 1 cm^3 of water equal to one gram at all temperatures. Here we ignore the variation of density of water with temperature.)

Specific heat. The number of calories of heat required to raise the temperature of one gram of a substance by one degree celsius is called the *specific heat* (s) of the substance (in the cgs system). In cgs units, we write it as s cal/g.°C or s cal g^{-1} $°\text{C}^{-1}$.

In the early stages of progress in physics, methods of measurement were not very refined. Many results were obtained by 'comparison'. The word 'specific' came to be used to express such results (compare 'specific gravity'). Though methods of measurement have vastly improved, we have not yet given up the use of the word 'specific'. Many modern authors use the term 'specific heat capacity'. The word 'specific' now carries the sense, 'per unit' mass or volume, etc., such as 'specific latent heat'.

On the basis of comparison, we had defined specific heat as the ratio

$$= \frac{\text{heat required to raise the temperature of } m \text{ grams of a substance by } t°\text{C}}{\text{,, ,, ,, ,, ,, ,, } m \text{ grams of water by } t°\text{C}}$$

$$= \frac{mst \text{ cal}}{mt \text{ cal}} = s.$$

In this definition s is a pure number without any unit attached to it. This is like specific gravity which is also a pure number.

We now consider it better to write s as s cal/g°C (or cal/g^{-1} $°\text{C}^{-1}$).

Heat capacity or Thermal capacity. The heat required to raise the temperature of a body by one celsius degree is called its *heat capacity* (*or thermal capacity*). Let m be the mass of the body in grams,

s cal/g.°C the specific heat of its material and the rise of temperature 1C°. Then the heat capacity (thermal capacity) Q of the body is $m(\mathrm{g}) \times s$ (cal/g °C)$=ms$ cal/°C. Note that the term 'specific heat' applies to a material and heat capacity or 'thermal capacity' to a body.

From the definition of heat capacity (thermal capacity) it follows that 'specific heat' of a substance is the heat capacity (thermal capacity) of one gram of the material. Hence the name 'specific heat capacity'.

Water equivalent. *The number of grams of water* which can be heated 1 celsius degree by an amount of heat equal to the heat capacity of a body, is called the *water equivalent* of the body. Water equivalent (W) means an amount of water in grams. If m is the mass and s the specific heat of the body W is numerically equal to ms. So $W=ms$ grams (g). Note that ms calories of heat raise the temperature of ms grams of water by 1C°. The word 'water equivalent' is rarely used in modern scientific writing. The term 'heat capacity' is more significant. 'Water-equivalent' was coined in the older days when we used specific heat as a ratio.

4-1.2. Calorimetry. There is no instrument which measures heat directly (as thermometer measures temperature). To measure a quantity of heat we measure several other quantities and calculate the amount of heat from those data. The vessel in which such measurements are made is called a **calorimeter.** It is generally a cylindrical vessel of copper which has a small heat capacity and a high thermal conductivity. The specific heat of copper is 0·09 cal/g.°C. The term **calorimetry** means measurement of heat.

Method of mixtures. The oldest method of calorimetry is the 'method of mixtures'. In this method bodies at different temperatures are 'mixed' together, so that all of them can acquire the same temperature. From the measured common temperature we can calculate the quantity we seek.

Principle of the method of mixtures. To principle states that *If no heat energy is allowed to enter nor leaves the calorimeter then the heat lost by the warmer bodies=the heat gained by the cooler bodies.* It follows from the principle of conservation of energy.

Exchange of heat between the calorimeter and the outside cannot be fully stopped. But if the calorimeter is surrounded by a bad conductor of heat, exchange of heat can be much reduced. Many precautions may be taken in the construction and the method of use of a calorimeter in order to minimize heat exchange. But at this early stage we shall not go into them. We shall use simple calorimeters and employ simple methods. The error in the result will be a little high; but that does not matter. It is more important that the student first learns to use measuring instruments properly. Accuracy of result will follow when more refined instruments are used.

Some liquid is taken inside a calorimeter. This makes it easier for the bodies inside it to exchange heat between themselves. Generally, water is used for the purpose. A 'stirrer' is used constantly to stir the water. The stirrer and the calorimeter are both made of copper.

4-2. Experiment 18

To determine the specific heat of a solid by the method of mixtures

Theory. Let

mass of calorimeter+stirrer $=m_1$ g;
mass of liquid in the calorimeter $=m_2$ g;
specific heat of the material of the calorimeter $=s_1$ cal/g. °C;
specific heat of liquid in the calorimter $=s_2$ cal/g. C°;
initial temperature of calorimeter and its contents $=t_1$ °C;
mass of the experimental body $=m$ g;
specific heat of the material of the body $=s$ cal/g. °C;
(This is the quantity to be determined)
initial temperature of the body $=t_2$ °C($>t_1$ °C)
common temperature of all the bodies (after mixing) $=t$°C.

The initial temperature (t_2) of the body is greater than that (t_1) of the calorimeter and its contents. So, when mixed, the body will lose heat$=ms\ (t_2-t)$ cal. The calorimeter and contents receive this heat and rise in temperature to t°C. The heat they so gain is $(m_1s_1+m_2s_2)\ (t-t_1)$ cal. Assuming that no heat has left nor entered the calorimeter, we shall have, from the principle of conservation of energy, that heat lost=heat gained,

or $ms\ (t_2-t)=(m_1s_1+m_2s_2)(t-t_1)$

$\therefore\ s=(m_1s_1+m_2s_2)(t-t_1)/m(t_2-t)$

[**Note**—Ask the teacher for the values of s_1 and s_2. If the calorimeter and stirrer are made of copper, s_1 may be taken as 0·1 cal/g.°C. For aluminium $s_1=0{\cdot}2$ cal/g.°C. $m_1 s_1 = W$ is the water equivalent of the calorimeter and stirrer.]

Apparatus. Steam-heater; Calorimeter and stirrer with non-conducting vessel; the experimental solid; two thermometers (one of range 0°→100°C; the other of 0°→50°C preferably with 5 divisions to the degree); balance with weight box.

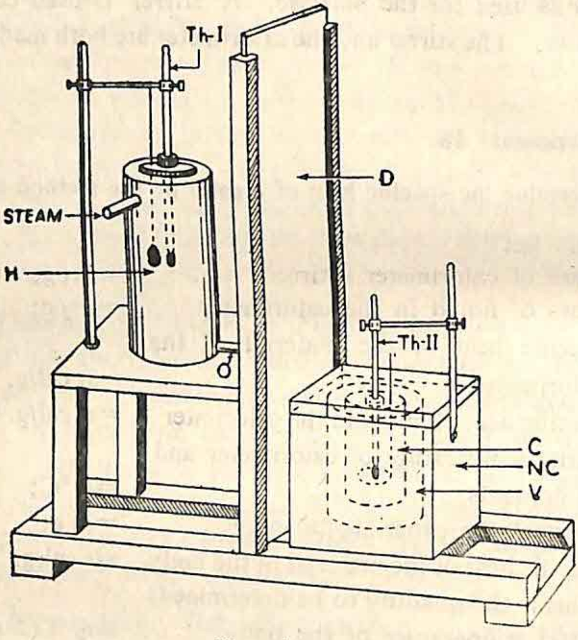

Fig. 4.1

[**Description of apparatus.** The calorimeter (*c*) is a relatively small cylindrical copper vessel (Fig. 4.1). It has a copper stirrer for stirring the water in the calorimeter. The calorimeter container (*V*) is a bigger cylindrical vessel of wood. It has a pad of felt or cork (*Nc*) at its bottom. The calorimeter is placed on this pad. The pad and the container reduce heat loss by conduction and convection.

To heat the body a steam chamber (*H*) with an inlet tube for steam entrance and an outlet tube for steam exit is used. There is a sliding wooden partition (*D*) by which transference of heat from heat chamber to the calorimeter is prevented. Thermometer I (0→100°C) is used to measure the temperature of the hot body and thermometer II (0°→50°C) is used to measure the temperature of the calorimetric liquid.]

[Directions for the experiment.

(1) Weigh the experimental solid (m_1 g). (m_1 may be determind to the nearest decigram. Finer weighing is unnecessary. In no case we shall require more than three significant digits. Because of uncertain heat losses, even the second digit in s will be uncertain.)

(2) Introduce the solid and the thermometer I in the steam chamber through the upper cork. Closed the lower-end of the chamber by the sliding board fixed in the system. Light the bunsen burner and allow the water to boil. The temperature of the steam chamber gradually increase and when the temperature reach nearly 100°C, it become steady. It should be steady for at least 10 minutes before you take out the solid.

(3) Without waiting for the water to boil, weigh the empty calorimeter with stirrer (m_1 g). It is enough to measure m_1 to the nearest gram.

(4) Put enough liquid in the calorimeter as would cover the experimental solid. Weigh the calorimeter with stirrer and liquid (m'_1 g). The mass of the liquid taken is $m_2=(m'_1-m_1)$g.

(5) Put the calorimeter inside its container, measure the temperature of the liquid in the calorimeter with the 50° thermometer. Use eye estimation to read the temperature to 0·1C degree (a tenth of a degree). This value is t_1 °C.

(6) Note the steady temperature of the steam chamber (t_2 °C).

(7) Bring the calorimeter with its contents just at the bottom of the steam chamber by opening the sliding partition and drop the solid into the calorimeter liquid by opening the sliding board at the bottom as quickly as possible. Be sure that it is fully immersed in the calorimetric liquid. Do not spill any liquid from the calorimeter.

(8) Continuously stir the liquid. See that the thermometer is not injured in stirring. Note the maximum temperature reached by the thermometer. Read the value to tenth of a degree by eye estimation. This maximum value is the common temperature t°C.]

Observations.

Given, specific heat (s_1) of the material of the calorimeter= ···Cal/g. °C.

specific heat (s_2) of the calorimetric liquid=···Cal/g. °C.

No. of obs	Mass of the Solid (m)	Mass of empty Cal. +Stirrer. (m_1)	Mass of empty Cal. +Stirrer+ liquid (m_1')	Mass of water taken $m_2=(m_1'-m_1)$	Initial temp. of liquid (t_1)	Temp.. of the heated solid (t_2)	Common Temp. after mixing (t)
1.	(..+..+..)g +(..+ +)mg =..g	(..+..+..)g +(..+..+..)mg =..g	(..+..+..+..)g +(..+....+..)mg =..g	..−.. =..g	..°C	..C°	..°C

Calculations.

Heat lost=ms (t_2-t) Cal=···×s cal.

Heat gained=$(m_1s_1+m_2s_2)(t-t_1)$=···Cal.

$$\therefore\ S=\frac{(m_1s_1+m_2s_2)(t-t_1)}{m(t_2-t)}=\frac{\cdots\text{cal}}{\cdots\text{g °C}}=\cdots\text{Cal/g. °C.}$$

Result.

The required value (s) of the specific heat of the given solid= ···cal/g. °C.

Method followed. (1) The experimental solid was weighed and suspended by a thread with a thermometer in the heat chamber. The water was put to boil.

(2) In the same time the empty calorimeter was weighed. It was then party filled with liquid and weighed again.

(3) The calorimeter was placed in its container and the temperature of liquid noted carefully.

(4) Having made sure that the temperature of the steam had been steady for at least ten minutes, its temperature was noted.

(5) The calorimeter with its contents was brought just at the bottom of the heat chamber and the solid was dropped into the calori-

matric liquid by opening the sliding board at the bottom quickly and carefully.

(6) Liquid in the calorimeter was continuously stirred. The maximum temperature reached by the thermometer in it was carefully noted.

Precautions.

(1) The time interval between taking the heated solid out of the heat chamber and putting it in the calorimeter was made as short as possible. No water spilled while putting the solid in the calorimeter.

(2) The water in the calorimeter was continuously stirred. Care was taken so that the thermometer was not injured in stirring.

(3) The calorimeter was kept screened from the heat radiated by the burner.

(4) In reading the thermometers, parallax error was avoided.

Remarks. (1) In such experiments, heat exchange between the calorimeter and the outside cannot be prevented. It can be reduced to a greater or lesser extent. But some heat is always transferred by conduction, convection and radiation. Moreover, in the little time lost in transferring the hot body to the calorimeter, some heat is lost by the body. For all these reasons, the result cannot be very accurate. Uncertainty persists in the second digit.

(2) Water has the highest specific heat among all ordinary substances. If water is taken as a calorimetric liquid then for a given supply of heat, its rise of temperature will be the smallest. So, just enough water should be taken in the calorimeter fully to immerse the solid and the thermometer bulb.

(3) The largest error occurs in measuring $(t-t_1)$, the temperature rise of liquid. In the case of water it is hardly 5C°. Each temperature reading may have an error of 0·2C°. The total error for two readings may be as high as 0·4C°. So for a temperature rise of even 5C°, the percentage error may be $(0{\cdot}4/5)\times100=8\%$. The error for heat exchange may be 5% depending on the situation. It is therefore not unlikely that the value you get will differ from the accepted value by 10 to 20%. If the error can be brought down to 5%, the result should be considered very good.

Oral questions. (1) What is specific heat? Whose specific heat are you determining?

(2) Is specific heat a pure number, or has it any unit attached to it?

(3) What is a calorie? Why is temperature mentioned in the definition?

(4) What is the harm if you allow heat exchange to take place between the calorimeter and the outside?

(5) What steps have you taken to reduce heat exchange?

(6) What is the principle on which the method of mixtures is based?

(7) What is the harm if you take more water in the calorimeter?

Answers. For (1), (2) and (3)—See Section 4-1.1. (4) The principle of the method of mixtures does not apply in that case (see Section 4-1.2). (5) The calorimeter has been placed on a bad conductor in a container. This reduces heat loss by conduction and by convection. Radiation loss cannot be prevented. But it can be reduced by polishing the outer surface of the calorimeter. There are methods of calculating losses by convection and radiation. But this 'radiation loss' method is not being employed here. (6) See Section 4-1.2. (7) Temperature rise will be smaller and the experimental error greater. See items (2) and (3) of the 'Remarks' above.

Specific heat (cal/g.°C)

Aluminium	0·21	Glass (Flint)	0·12
Brass	0·089	Marble	0·21-0·22
Copper	0·091	Porcelain	0·18
Glass (crown)	0·16	Sand	0·19

4-3. Latent heat.

To melt a solid it must be heated to its melting point and then some additional heat added to it. Unless the solid gets this additional heat while at its melting point, it will not melt. During melting the temperature remains fixed at the melting point. (The last statement applies to a pure crystalline substance; not to mixtures or impure substances.)

Similarly, when a liquid is to be converted into vapour by boiling, it must be raised to its boiling point and more heat added to it. Unless the liquid gets the additional heat at its boiling point, it will not boil. In the case of a pure liquid, its temperature will remain constant while it is boiling.

The heat required by unit mass of a solid substance to be converted into the liquid state without change of temperature is called the *latent heat of fusion* of the substance.* In cgs units, it is expressed in *calories per gram* (cal/g). The statement that 'the latent heat of ice is 80 cal/g' means that if ice is at its melting point (0°C), it will require

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*A better and more modern term is **specific latent heat.** It means latent heat per unit mass.

an addition of 80 calories for each gram of ice to melt. The water formed will also be at 0°C. During melting the temperature will remain constant at 0°C. (If no heat is added to or removed from a mixture of ice and water at 0°C, both ice and water will remain unchanged.) When water at 0°C solidifies into ice at 0°C, each gram of water *gives out* 80 calories of heat.

The heat required by unit mass of a liquid to be converted into the vapour form without change of temprature is called its *latent heat of vaporization*. The same quantity of heat is given out when the vapour condenses.

In the next experiment we describe how the latent heat of ice can be measured.

4-3.1. Experiment 19.

To determine the latent heat of fusion of ice

Theory. Let

Mass of the empty calorimeter $= m_1$ g
Specific heat of its material $= s_1$ cal/g. °C
Mass of water in the calorimeter $= m_2$ g
Initial temperature of the water $= t_1$ °C
Mass of ice melted in the water $= m$ g.
Minimum temperature of water after the ice in it has melted $= t$ °C
Temperature of melting ice $= 0$° C
Latent heat of ice $= L$ cal/g

If there is no heat exchange between the calorimeter and the outside, we shall have

heat lost = heat gained.

In this case ice has gained heat in melting. The calorimeter and its contents have given up heat in cooling. Thus

Heat gained = latent heat taken in by ice at 0°C in melting + heat required by the water formed in rising from 0°C to t°C $= (mL + mt)$cal.

Heat lost = Heat given up by calorimeter with contents in cooling from t_1 °C to t°C $= (m_1 s_1 + m_2 .1)(t_1 - t)$ cal.

$$\therefore \quad mL + mt = (m_1 s_1 + m_2)(t_1 - t)$$

$$\text{or } L = \frac{(m_1 s_1 + m_2)(t_1 - t)}{m} - t \text{ (cal/g)}$$

Apparatus. Calorimeter with a net-covered stirrer; container for calorimeter; thermometer (0°→50°C; preferably graduated in one-fifth of a degree); small lumps of ice; blotting paper; water; common balance with weight box.

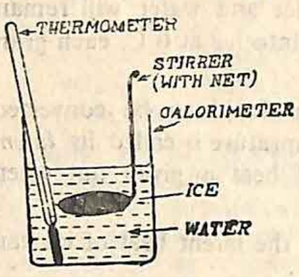


Fig. 4.2

[Directions for the experiment.

(1) Weigh the dry, empty calorimeter with stirrer (m_1 g). The specific heat s_1 may be had from the teacher.

(2) Half fill the calorimeter with water and weigh it with the stirrer (m'_1 g). Mass of water taken $=(m'_1-m_1)$ g$=m_2$ g. Put the calorimeter in its container.

(3) Ascertain from the teacher the value t_d of the dew point. Note the temperature of the water in the calorimeter to tenths of a degree using eye estimation.

(4) Absorb with a piece of blotting paper the water adhering to a lump of ice. Quickly drop the dried ice into the calorimeter. See that no water is spilled in the process. Press the ice under water with the net-covered stirrer (Fig. 4.2) and stir the water. Note the temperature of the water. Go on adding lumps of ice in this manner until the thermometer reaches a temperature a little above the dew point.

(5) Stop adding ice, stir the water well and note the minimum temperature reached by the thermometer. Use eye estimation to get this temperature to tenths of a degree.

(6) Weigh the calorimeter again (m_1''g). Then the mass of ice melted is $(m_1''-m_1')=$m g.]

Observations. Specific heat of the material of the calorimeter (given) =...Cal/g. °C Dew point=···°C

No. of obs.	Mass of empty Cal.+stirrer (m_1)	Mass of Cal.+Stirrer+water initially taken (m_1')	Mass of water initially taken $m_2=(m_1'-m_1)$	Initial temp. of water (t_1)	Minimum temp. reached by the water (t)	Mass of Cal.+stirrer+water+ice (m_1'')	Mass of melted ice $m=m_1''-m_1'$
1.	(..+..+..)g +(..+..+..)mg =..g.	(..+..+..+..)g +(..+..+..) mg=..g.	..g−..g =..g	..°C	..°C	(+..+..+..)g +(..+..+..) mg=..g	..−.. =..g.

Calculation.

Heat gained by ice $= \cdots$ cal $(mL+mt)$

Heat lost by calorimeter with contents $= \ldots$ cal $(m_1s_1+m_2)(t_1-t)$

$$\therefore \quad mL+mt=(m_1s_1+m_2)(t_1-t)$$

$$\text{or} \quad L=\frac{(m_1s_1+m_2)(t_1-t)}{m}-t \qquad = \cdots \text{ cal/g}$$

Result.

The latent heat of ice (L) $= \cdots$ cal/g.

Method followed.

(1) The dry calorimeter with stirrer was weighed empty. The specific heat of its material was supplied by the teacher.

(2) The calorimeter was half-filled with water and the mass of the water determined by weighing again. The calorimeter was then placed in its container.

(3) The room temperature and dew point were ascertained from the laboratory.

(4) Before adding ice the temperature of water was noted to tenths of a degree by eye-estimation.

(5) Small lumps of ice were added to the water one by one after drying each with a piece of blotting paper. Each lump was melted under water with the help of the net-covered stirrer. Addition of ice was stopped when the temperature came down near the dew point.

(6) The water was thoroughly stirred. The minimum temperature reached by the thermometer was read to tenths of a degree using eye-estimation.

(7) The mass of the ice added was determined by weighing the calorimeter again.

Precautions.

(1) Before a lump of ice was added, the water sticking to it was removed by soaking it with a piece of blotting paper. (Failing to do it will increase the apparent mass of ice added. But the real mass of ice will be less. This will reduce the observed value of L.)

(2) The minimum temperature was not allowed to reach the dew point. (If dew point is reached or exceeded, dew will be deposited on the calorimeter. The deposited dew will give its heat of condensa-

tion to the calorimeter. So the calorimeter will get an extra supply of heat. This cannot be taken into account. This will also reduce the value of L.)

(3) The water was carefully stirred all along.

(4) In reading the thermometer parallax error was avoided.

[Special remarks.

(1) Let the *dew point* at the time of the work be lower than the initial temperature of the calorimeter water by t'C°. The calorimeter is not allowed to cool below the dew point. Start the experiment by heating the calorimeter water t' C° above the room temperature. In such a case, the calorimeter will lose as much heat to the outside when it is warmer as gain when it is cooler. The heat exchanges will nearly neutralized each other.)

(2) The experiment may not be set on a *moist day*, such as during rains. When humidity is high the dew point is close to the room temperature. The fall in temperature of water will be small. The mass of ice added will also be small. So the risk of error in the result will increase further.

The accepted value of the latent heat of fusion of ice is 79.7 cal/g.]

Oral questions. (1) What is latent heat? In what unit is it expressed? Whose latent heat are you determining?

(2) What is the principle of the method of mixtures?

(3) Define the calorie.

(4) What is the harm if heat enters the calorimeter?

(5) How can you reduce heat exchange between the calorimeter and its surroundings?

(6) What is dew point? What is the harm if ice cools the water below the dew point?

(7) Why have you kept the calorimeter in its container?

Answers (1) See Section 4-3. I am determining the latent heat of fusion of ice. (2) See Section 4-1.2. (3) See Section 4-1.1. (4) We cannot then apply the relation that heat lost=heat gained. (5) If the calorimeter temperature is above the room temperature it loses heat. If it is lower than room temperature it gains heat. The loss or gain is proportional to the temperature difference. In the experiment if mean temperature of the calorimeter equal to the room temperature, then heat loss and heat gain nearly balanced each other. (6) The temperature at which the moisture in the air will saturate it, is called the dew point. See item (2) under 'Precautions'. (7) To reduce the heat gain by conduction and convection.

CHAPTER 5

SOUND

5-1. Introductory remarks on 'SOUND' experiments.

In connexion with sound experiments, it is conveneint to have an elementary idea of (*a*) forced vibration, (*b*) resonance and (*c*) stationary (or standing) waves.

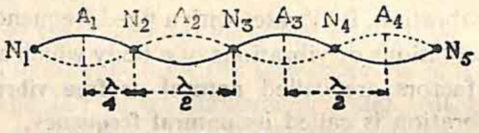
(*a*) **Forced vibration.** When a pendulum is set into oscillation, it oscillates with a fixed frequency. When a clamped strip of steel is set into vibration, it vibrates with a fixed frequency characteristic of its own. Oscillations or vibrations of a body which are not influenced by outside factors are called **natural** or **free vibrations** and the frequency of vibration is called its **natural frequency.**

If you tie a string to the pendulum bob and pull it periodically as you like, the pendulum cannot oscillate in its own natural way. Its oscillations are controlled by your periodic pulls. This kind of oscillation or vibration is called **forced vibration.** (Note that there is no particular difference between the words 'oscillation' and 'vibration'.)

A body, free to oscillate in its own way, does so with a frequency characteristic of its own. These are 'free' vibrations. But if a periodic force of some other frequency makes it vibrate, it vibrates with the frequency of this 'driving' force. Such vibration is forced vibration. In forced vibration, the amplitude of vibration is generally small (unless you apply a large driving force).

(*b*) **Resonance.** When the frequency of the driving force is equal to the natural frequency of the driven body, the amplitude of vibration increases greatly. The driver transfers maximum energy to the driven body. You must have seen a child in a swing giving periodic impulses to it. If the impulses are properly timed, the swing acquires a large amplitude. It is a case of resonance. When the driving force has the same frequency as the natural frequency of a body, **resonance is** said to occur between them.

(*c*) **Stationary waves.** The vibrations that occur in a medium when two identical waves, moving from opposite directions, are superposed (that is, fall on each other), are called **stationary** (or **standing**) **waves.** By 'identical waves', we mean waves of the same amplitude and frequency (and, of course, velocity). In stationary waves, you will find that along the line of progress of the waves there are points at equal intervals at which there is no motion. Such points always remain at rest (stationary) and are known as **nodes.** Between two nodes the amplitude of vibration of particles of the medium gradually increases. It reaches the maximum value just midway between the nodes. Such points of maximum amplitude are called **antinodes.** The distance between two successive nodes or two successive antinodes is $\lambda/2$, where λ is the wavelength of the superposed waves. Between a node and its nearest antinode the distance is $\lambda/4$ (See Fig. 5.1).



Fif. 5.1

(Pattern of standing waves. N=node, A=antinode. Distance between curved lines gives the range of motion of a particle of the medium. It is twice the amplitude.)

5-1.1. The tuning fork. In all experiments on sound, the tuning fork is an essential instrument. It is a U-shaped bar of steel with an attached handle (Fig. 5.2*a*). When struck on a pad of rubber or felt, it vibrates with a *single, fixed frequency* (which depends on the size and material of the fork). The frequency is generally stamped on the fork. Low frequency forks are bigger. High frequency forks are smaller in size.

The nature of vibration of a fork has been shown in Fig. 5.2(*b*). Both of its arms (called *prongs*) move inward (position 1) or outward (position 2) at the same time. Low down each arm there is a point (N) which never vibrates. It is a node. The bend between the nodes moves up and down as the fork vibrates. This

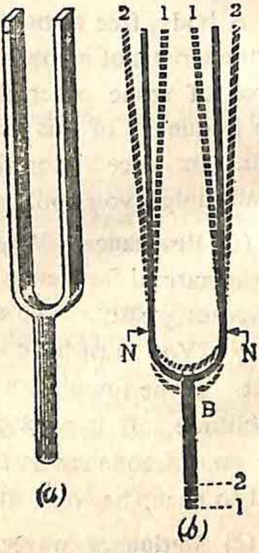


Fig. 5.2

can be understood from the figure. As a result of such movement of the bend, the handle of the fork also moves up and down as the fork vibrates.

The up-and-down movement of the handle is very important for the action of the fork. When the handle of a vibrating fork is pressed on a wooden board, the board will be thrown into forced vibration by the fork. The frequency of vibration will be that of the fork.

The fork itself is a feeble source of sound. You can see it for yourself by holding a vibrating fork by the handle. The fork stirs a small mass of air. Hence the feebleness of the sound. But when pressed on a board, the board causes a much larger mass of air to vibrate. Hence the sound becomes louder. But, as the fork expends energy at a faster rate, its vibrations die away quickly.

Precaution in the use of a tuning fork. Never strike the fork on a table or on any hard body. It is best to use a pad of rubber or felt. Striking on a hard substance may cause a prong to break. Besides, when struck hard a fork gives an unwanted high-pitched sound which has a much higher frequency than the one marked on the fork.

5-12. The Sonometer. Another very useful instrument in sound experiments is the *Sonometer*. Its construction may be understood from Fig. 5.3. A of the figure is a hollow wooden box. A steel wire is fixed to a peg at one end of the box. At the other end there is a pulley over which the wire passes. A hanger is attached to the free end of the wire. On this hanger you can place weights. This keeps the wire under tension. The wire rests on two movable bridges (B_1, B_2) on the box.

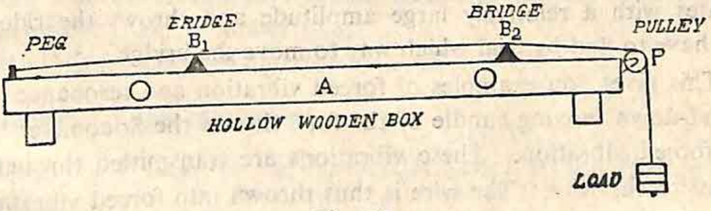


Fig. 5.3

The portion of the wire between the bridges can be made to vibrate by pulling it slightly to one side near its middle. A vibrating wire of length l and tension T gives out a note of fixed frequency. If the whole wire (between the bridges) vibrates in one segment and its mass per unit length is m, then the frequency n is given by

$$n=\frac{1}{2l}\sqrt{\frac{T}{m}} \qquad (5\text{-}1.1)$$

If the tension is due to a total load (hanger + weights) of W g-wt, then $T=Wg$ where g is the acceleration due to gravity.

l can be altered by moving the bridges of the Sonometer. T is determined by the weights we put on the hanger. m depends on the diameter (d) of the wire and the density (ρ) of its material. ($m=\frac{1}{4}\pi d^2\rho$).

Tuning a sonometer wire. In experiments using a Sonometer, the vibrating wire has to be given a frequency equal to that of a fork. This can be done by altering l or T or both. The way of doing so is called *tuning*. The vibrating fork is pressed on the Sonometer board. The notes emitted by the fork and the string are heard alternately. When they seem to have about the same pitch, the frequency of the wire is adjusted finely to exact resonance. There are two ways of doing so.

(*i*) *The 'paper rider' method.* Take a very small piece of paper, shape it into a small Λ and place it on the wire in its middle. Press the vibrating fork on the sonometer. Move one of the bridges slowly to find the correct resonating length. When resonance occurs, the wire vibrates with a relatively large amplitude and throws the rider off. You have to find by trial which way to move the bridge.

(This gives you examples of forced vibration and resonance. The up-and-down moving handle of the fork throws the Sonometer board into forced vibration. These vibrations are transmitted through the bridges to the wire. The wire is thus thrown into forced vibration at first. But when its frequency has been adjusted to be the same as that of the fork, resonance occurs between the two. The amplitude of vibration of the wire gradually increases.)

(*ii*) *By counting 'beats'*. When two notes of nearly equal frequencies are sounded together, the sound heard appears to rise and fall in loudness. Each rise-and-fall is called a *beat*. The number of beats occurring per second is equal to the difference of frequencies of the two notes. Occurrence of 5 or 6 beats per second can be recognized even by an untrained ear.

Try to detect beats between the fork and the wire by vibrating them together. For this you have to adjust a bridge slowly by trial. Then adjust the bridge further till the beats fall in number and finally disappear.

5-2.1. Experiment 20

To determine the frequency of a tuning fork using a Sonometer and other forks of known frequency

Theory. Let a piece of wire of variable length l vibrate in one segment under a fixed tension. Then the relation between l and its frequency of vibration n is $n \times l$=constant. Suppose we have several forks of known frequencies $n_1, n_2\, n_3$, etc. If l_1, l_2, l_3, etc. be the lengths of a sonometer wire under fixed tension which resonante with the forks respectively, then

$$n_1 l_1 = n_2 l_2 = n_3 l_3 \text{ etc.} = \text{k (say)}.$$

If a length l of the wire resonates with a fork of unknown frequency n, then $n\,l = k$. Thus n may be determined.

[n vs. $1/l$ graph, or log n vs. log l graph is a straight line. The unknown frequency can be determined from any of these graphs. The graph n vs. l is a rectangular hyperbola. It is not suitable for determination of an unknown n].

Apparatus. Five forks of known frequency (256, 320, 384, 426, 512 cps are suitable values. Such sets are commercially available); the fork of unknown frequency; sonometer; a set of $\frac{1}{2}$ kg weights (for applying tension); thick rubber pad.

The Sonometer has been described in Section 5-12.]

[Directions for the experiment.

(1) Place the bridges of the Sonometer about 80 cm from each other.

(2) Take the fork of the lowest frequency. Increase the tension in the wire till the pitches of the fork and of the wire between the bridges appear closest.

(3) Tune the wire by moving one (or both) of the bridges till resonance with the fork occurs (See Section 5-1.2).

(4) Note the frequency n of the fork and the resonating length l (cm) of the wire. [Frequency is expressed in cps (cycles per second) or Hz(hertz) unit.]. Distrurb the bridge and take another reading with the same fork.

(5) Keep the tension T unchanged. Find the resonating lengths for the other forks and note the corresponding frequencies and lengths.]

Observations and Calculations.

n (cps or Hz)						
l(cm)	(*i*) .. (*ii*) ..					
Mean l (cm)	..					
$1/l$ (cm^{-1})						

(Express $1/l$ in decimals up to three significant digits.)

Plot n along the x-axis and $1/l$ along the y-axis. The graph should be a straight line (Fig. 5.4).

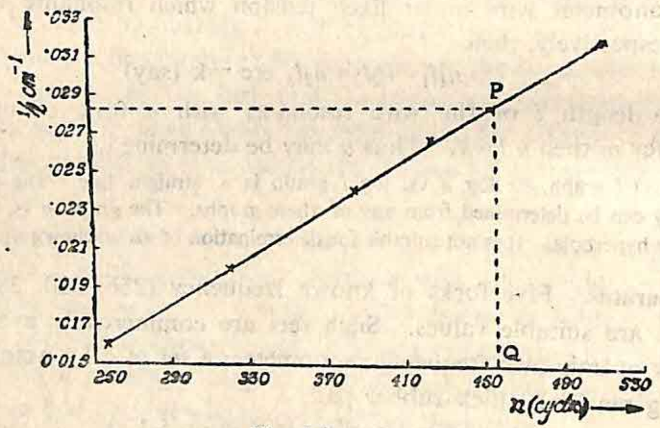


Fig. 5.4

Note the value of $1/l$ of the fork of unknown frequency. Find the point P on the graph whose y-coordinate has this value. Note the value of the x-coordinate (Q) of this point. The frequency represented by the position of Q is the unknown frequency.

Result. From the graph, it is found that the unknown frequency to be determined$=\cdots$cps. (or Hz).

Alternative method of calculation

[We know that the product $n \times l$=constant for a fixed tension. So, by taking the mean value of the product and dividing it by the resonating length for the unknown frequency, we can calculate the latter. For this purpose, we may tabulate as follows.]

Observations and Calculations.

n (cps)						
l (cm)	(*i*) (*ii*)					
Mean l (cm)						
$n \times l$						

The average value of $n \times l = \cdots(\text{cps} \times \text{cm})$

l for the unknown frequency $= \cdots$cm

Result.

$$\text{The unknown frequency is, therefore,} = \frac{\cdots \text{cps} \times \text{cm}}{\cdots l \text{ cm}}$$

$$= \cdots \text{cps.}$$

[This method of calculation does not require a graph to be drawn. The result can be retained up to three significant digits. Unless the graph paper is large, it cannot give a result up to three significant digits.]

Method followed.

(1) The bridges of the Sonometer were placed about 80 cm from each other.

(2) The tension in the wire was gradually increased till the pitch of the wire came closest to that of the fork.

(3) The tension was kept fixed at this value. One of the bridges was then slowly moved till resonance occurred between the wire and the fork. The resonating length and the frequency of the fork were noted.

(4) Operation (3) was repeated for all the forks including the one of unknown frequency.

Precaution.

The forks were always struck on the rubber pad.

[**Instructions for drawing the n v. $1/l$ graph.**

Suppose the values of n, l, and $1/l$ are as follows:

n	256	320	384	426	512
l	62.8	50.2	41.8	37.7	31.4
$1/l$	0.0159	0.0199	0.0239	0.0265	0.0318

Let us assume that the available graph paper has 60 small squares along one axis and 70 along the other. n varies from 256 to 512. So, one axis of the graph must represent at least (512—256)=256 frequency units (cps or Hz). $1/l$ varies from 0.0159 to 0.0318. So, the other axis has to represent at least (0.0318—0.0159)=0.0159 units (of cm^{-1}). We can plot n along the axis which has 70 divisions (small squares). Let each division represent 4 units of n. Then we can plot $4 \times 70 = 280$ n-units along this axis. This is enough for our purpose, for we need to plot only 256 n-units. If we take the lowest division mark on this axis to represent 250 of n, we can go up to $250+280=530$ of n along this axis. Certainly, this is enough for the purpose.

Along the other axis, 60 divisions should cover 0.0159 units. If we take 1 div.=0.003 unit, we can cover values up to $60 \times 0.003 = 0.180$. In order to go up to 0.0318 along this axis, we can take the lowest division mark to represent 0.0150. Thus we can cover a range from 0.0150 to $(0.0150+0.0180)=0.0330$. Our actual range is 0.0159 to 0.0318. So this is good enough.

Choice of units and ranges in this manner will utilize most of the graph paper. Units are so chosen as to make plotting of a value easy.

Choice of units and ranges in this manner will utilize most of the graph paper. Units are so chosen as to make plotting of a value easy.

The graph so drawn is shown in Fig. 5.4.

Remarks. To find n from an n-l graph will be less accurate than doing so from an n-$1/l$ graph. The latter is a straight line and easy to draw without deviating far (going far away) from the true value. But the n-l graph is a curve called a rectangular hyperbola. In drawing a curve chances of deviation are far greater than for a straight line.

Oral questions. (1) Describe the action of a tuning fork.

(2) How does it make the wire of the Sonometer vibrate?

(3) On what factors does the frequency of a vibrating wire depend?

(4) A vibrating fork held by the handle between two fingers gives a low sound. But when the handle is pressed on a board the sound is much louder. Explain why. Why do the vibrations die away quicker in the latter case?

(5) If the tension of a wire is increased, will the length of a wire in resonance with a fixed frequency increase or decrease?

Answers. (1) See Section 5-1.1. (2) The sonometer board is thrown into forced vibration by the up-and-down motion of the handle of the fork. These vibrations are transmitted through the bridges to the wire (see paragraph following item (i) under Section 5-1.2). (3) See Section 5-1.2. (4) See the fourth paragraph of Section 5-1.1. (5) From Eq. 5-1.1., it can be seen that when n is constant, l must be increased if T increases.

5-2.2. Experiment 21

To determine the frequency of a fork using a Sonometer and no other fork

Theory. Let n (cps or Hz) be the frequency of vibration of a wire of length l cm and mass m per centimetre under a tension of T dynes. These quantities are related by the equation

$$n=\frac{1}{2l}\sqrt{\frac{T}{m}}$$

Measuring l, T and m, we can calculate n. If this wire is in resonance with the given fork, then n is also the frequency of the fork.

Apparatus. Sonometer; a set of $\frac{1}{2}$kg weights; the experimental fork; chemical balance with weigh box; rubber pad.

[For *construction* and *action* of a sonometer See Section 5-1.2.]

[**Directions for the experiment.**

(1) Apply at first a tension of 2 kg-wt to the sonometer wire.

(2) Move one of the bridges to bring the pitch of the wire (between the bridges) as close as possible to that of the fork. Then tune the wire to resonance (Sec. 5-1.2.). (If l is less than 25 cm, increase the tension and tune again.)

(3) Note the resonating length (l cm) and the total weight (W g-wt) that causes the tension. W should include the weight of the hanger.

(4) Disturb the tuning by moving one of the bridges. Tune again. Note l three times in this way. W should remain the same.

(5) Ask for a sample of wire from the laboratory which is the same as the sonometer wire. Measure its length L (cm). Find the mass M of this sample accurately on a chemical balance. (Weigh to to the nearest milligram.)

Observations.

Mass of the hanger (w') = ... g

Length of the Sample wire cm	Mean length L cm	Mass of the sample wire M g	$m=\frac{M}{L}$ g/cm.	Tensin of the string $T=*W\times980$ dynes	Resonat-ing length cm	Mean resonating length (l) cm
(*i*) ..		(..+..+			(*i*)	
(*ii*) ..	..	..)g+(..+			(*ii*)	....
(*iii*) ..		..+..)mg =..g	..	..	(*iii*)	

* $W=(w+w')$; w=weight on the hanger.

Calculations.

Mean value of $l = \cdots$ cm.

$T = W \times 980$ dyn $= \cdots$ dyn.

$$m = \frac{M}{L}\ \frac{\text{g}}{\text{cm}} = \cdots \text{g/cm}.$$

$$\therefore\ n = \frac{1}{2l}\sqrt{\frac{T}{m}} = \cdots \text{cps}.$$

Result. The frequency of the fork $(=n) = \cdots$ cps.

Oral questions and Answers.

(As in Experiment 20)

5-3. Resonance tube.

A *resonance tube* here means a glass tube of diameter about 5 cm. One end of the tube is closed by water. The length of the air column in the tube above the water level may be increased or decreased by raising or lowering the tube or the water reservoir. The mechanical arrangement may be of two kinds shown in Figs. 5.5(*a*) and 5.5(*b*).

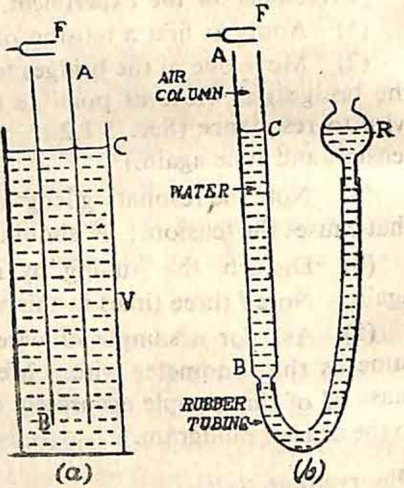


Fig. 5.5

In Fig. 5.5(*a*) AB is the glass tube, V is a deep vessel containing water and F is a fork of known frequency. The length of the air column in the tube can be altered by raising or lowering AB. This length can be measured with a metre scale.

In Fig. 5.5(*b*), AB is a wide diameter glass tube, about one metre long. Its lower end B is narrow. B is connected by a rubber tube with a water reservoir R. R may be raised or lowered at will and kept fixed at any desired level. A metre scale, placed close to AB, measures the length of the air column. The zero of the scale coincides with the upper end of AB.

The second arrangement has an advantage over the first, as we shall see later.

5-3.1. Action of the resonance tube. Hold a vibrating fork over the open end of the tube. Sound waves entering the tube will be reflected from the water at the lower end. This causes superposition of two identical waves moving in opposite directions in the tube. As a result stationary waves are formed in the tube (See Section 5-1c). At the water level C, the air particles cannot vibrate. So a node is always formed at C. The air particles at the open end A are perfectly free to move. So an antinode will be formed at A. The shortest distance between a node and its nearest antinode is $\lambda/4$ (Section 5-1c). If, therefore, the length l of the air column is $\lambda/4$ (λ=wavelength of the waves produced by the fork in the tube), there will be resonance between the waves and the tube, and a loud sound will be emitted. For this reason the tube is called a 'resonance tube'.

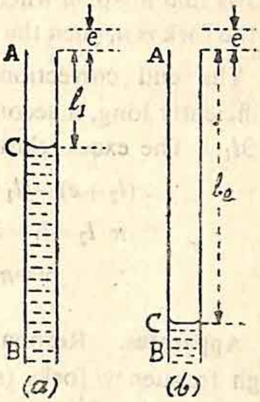


Fig. 5.6

In the arrangement of Fig. 5.5(*b*), the first resonance occurs when $l_1=\lambda/4$. A second resonance occurs near a length l_2 equal to about $3l_1$. The condition for it is approximately $l_2=3\lambda/4$.

5-3.2. End correction. When the air column AC vibrates, the antinode is formed not exactly at A, but a little away from it. Lord Rayleigh has calculated this distance to be $e=0.3d$ where d is the diameter of the tube. In Fig. 5.5(*a*), $\lambda/4=l_1+e$ and in Fig. 5.6(*b*), $3\lambda/4=l_2+e$. The distance e is called the *end correction*. End correction can be eliminated by using two resonances in the same tube. This requires a longer tube. The second arrangement is therefore suitable for elimination of end correction.

5-4. Experiment 22

To determine the velocity of sound in air with a resonance tube

(By elimination of end correction.)

Theory. If the first resonance occurs at a length l_1 of a resonance tube (Fig. 5.6*a*) we have $l_1+e=\lambda/4$. λ is the wave length of the waves emitted by the vibrating fork and e is the end correction. Calculation shows that $e=0.3d$ where d is the diameter of the tube. If the frequency of the fork is n, then the velocity of sound in the tube$=v=n\lambda$.

The end correction can be eliminated. If the resonance tube is sufficiently long, a second resonance occurs at a length l_2 about equal to $3l_1$. The exact relation is $l_2+e=3\lambda/4$.

$$\therefore \quad (l_2+e)-(l_1+e)=3\lambda/4-\lambda/4$$

$$\text{or } l_2-l_1=\lambda/2$$

$$\therefore \quad v=n\lambda=2n(l_2-l_1).$$

Apparatus. Resonance tube with accessories (Fig. 5.5*a*, *b*); two high frequency forks (say, of 480 and 512 cps); water; metre scale; rubber pad; thermometer.

(Description of the apparatus has been given in Section 5-3.)

[Directions for the experiment.

(1) Arrange the apparatus which you get (Fig. 5.5*a* or 5.5*b*).

(2) Start by having the water level near the upper end of the resonance tube. Take the fork, vibrate it and hold it near the mouth of the tube. Maintain the vibrations by striking the fork on the pad as often as necessary. Go on slowly increasing the length of the air column. (Raise the tube if your apparatus is like Fig. 5.5*a* or lower the reservoir if it is like Fig. 5.5*b*.)

(3) Listen carefully and note when sound from the tube begins to be loud. Adjust the length for maximum loudness and note the length l_1 of the air column. Disturb the length and measure l_1 again.

(4) Look for the second resonance at a tube length of about $3l_1$. Find the exact value of l_2 and measure it twice. Note the frequency of the fork used.

(5) Repeat operations (2), (3) and (4) for the second fork.

(6) Note the temperature of the room or of the water in the tube.

(7) If you are given only one fork, measure l_1, l_2 at least thrice each.

Observations and Calculations

No. of obs.	Frequency of the fork n(cps or Hz)	First resonant length l_1 cm.	Mean l_1 cm.	Second resonant length l_2 cm	Mean l_2 cm.	Velocity of sound $v=2n(l_2-l_1)$ cm/s.
1.	....	(*i*) .... (*ii*) .... (*iii*)	..	(*i*) .... (*ii*) .... (*iii*)	*M*	....
2.						
3.						
:						
etc.						

Room temperature (or temperature of water)=···°C (t°C)

Result. The mean value of v=···cm/s at...°C.

(Since not more than three digits are significant, better express the value in m/s.)

Method followed.

(1) The vibrating fork was held near the mouth of the resonance tube. The tube length was slowly increased from its lowest value. Whenever the fork was inaudible, it was vibrated again.

(2) The length of the air column below the vibrating fork was slowly increased in this way till the first resonance occurred. The exact tube length l_1 for maximum resonance was carefully determined and measured. The length was disturbed a little and l_1 measured again.

(3) The length of the air column was increased to about $3l_1$, and search made for the second resonance. When this was obtained, l_2 was carefully measured. The adjustment was slightly disturbed and l_2 determined again.

(4) The frequency of the fork used was noted.

(5) The same operations were repeated with the other fork.

(6) Temperature of the water in the tube was noted.

Precautions. (1) To get the first resonant length, the length of the air column should be increased from a very low value. (2) The frequency of the fork should be high, otherwise the 2nd resonant length will not be obtained.

[**Remarks.** (*i*) The velocity of sound in dry air at 30°C is about 350 m/s. The velocity depends a little on the amount of moisture in the air. In moist air sound travels faster. The velocity also increases with increase in temperature. So in different seasons in our country, the value differs as both temperature and moisture content change. The value in dry air at 0°C has been carefully measured. It is 331.5 m/s. It does not change with pressure.

(*ii*) In our resonance tube the value would be around 350 m/s. The air in the tube is saturated with moisture. If we knew the vapour pressure of water in the tube and the atmospheric pressure, we could calculate the value in dry air at the temperature of the experiment. The value could finally be reduced to that at 0°C. But this is no part of our present work.

(*iii*) For a fork of $n=256$ cps, l_1 would be about $350/(4\times256)$ m or about 34—35 cm. A resonance tube of length 1 metre will not be long enough for the second resonance. With $n=512$ cps the first resonance will occur around 17—18 cm. So we can expect to get the second resonance only with a high frequency fork.

(*iv*) A high frequency fork has short arms. Its vibrations die away quickly. It has therefore to be very frequently sounded as we slowly change the tubelength. Low frequency forks have longer and heavier arms. Their vibrations last longer.

(*v*) The loudness of the sound at second resonance is lower than that at the first. Here resonance occurs between the fork and the third harmonic of the air column. (The third harmonic has a frequency thrice that of the fundamental.)]

Oral questions. (1) Which is the resonance tube? Why is it so called?

(2) What is resonance? Which are the resonating bodies? Which are the resonating frequencies?

(3) Explain the terms *stationary waves*, *nodes* and *antinodes*.

(4) Where in the tube have we got nodes and antiondes?

(5) How are stationary waves formed in the tube?

(6) In stating your result why should you mention that the velocity is in 'moist air' and at a certain temperature?

(7) You are given forks of different frequencies to select from. What factor or factors would determine your choice of fork for the present work?

Answers. (1) The long tube of wide bore. Because resonance occurs with the air column it contains. (2) See Section 5-1(b). The resonating bodies are the fork and the air column. The resonating frequencies are that of the fork and a natural frequency of the air column. (3) See Section 5-1(c). (4) and (5)—See Section 5-3.1. (6) See item (i) under 'Remarks' above. (7) A heavy fork is preferable because its vibrations are louder and last longer. See items *(iii)*, *(iv)* and *(v)* under 'Remarks'.

5-5. Experiment 23

To Determine the frequency of a tuning fork by its resonance with air column velocity of sound being supplied.

Theory. Same as expt. 22. In the last column write

$$n=\frac{V}{2(l_2-l_1)}$$

Apparatus. Same as expt. 22.

[**Directions for experiment.** Same as expt. 22. Leave item nos. (5) and (7) and last line of item no. 4]

Observation and Calculations

velocity of sound at room temperature···°C=···cm/s (given)

First resonant length l_1 in cm.	Mean l_1 in cm.	Second resonant length l_2 in cm.	Mean l_2 in cm.	Frequency of the given fork $n=\frac{V}{2(l_2-l_1)}$
(i)		*(i)*		
(ii)	....	*(ii)*	....	$n=\frac{\ldots\ldots}{\ldots\ldots}$
(iii)		*(iii)*		

Result. The frequency of the given fork=···Hz

Method followed. Same as expt. 22. Leave item nos. (4) and (5).

Precautions. Same as expt. 22.

For oral questions and answers see expt. 22.

CHAPTER
6

MAGNETISM

6-1.1. Introductory remarks on MAGNETISM experiments. We should know the meanings of a few related terms before we start work.

(*a*) **Poles.** The regions, near the ends, where the attractive power is strongest are known as the poles of the magnet. For Simplicity we treat them as points.

(*b*) **Magnetic field.** A region in which a magnetic force is felt is called a *magnetic field.*

(*c*) **Magnetic field strength or Magnetic intensity.** The force in dynes which a unit north pole experiences at a point in a magnetic field is called the *strength* or *intensity of the magnetic field* at that point. The direction in which this force acts is called the direction of the field at the point.

(*d*) **Magnetic lines of force.** We can define it in two ways, both of which mean the same thing. (*i*) A line of force in a magnetic field is a line the tangent to which at any point gives the direction of the field at that point. (*ii*) A line of force in a magnetic field is the path which an inertialess, free, north magnetic pole would follow if released in the field. An inertialess, free pole is an object of imagination,

When a small compass needle is placed in a magnetic field it sets itself tangentially to the line of force at the place. Its north pole tends to move forward along the line of force. The south pole tends to move in the opposite direction. Under the action of these two forces the compass needle sets itself along the line of force if it is short enough. If the lines are curved, the needle sets itself tangentially to the line through its centre. *This property of the needle is the basis for drawing lines of force.* The direction in which the north pole of a magnetic needle points in a magnetic field is the direction of the field or of the line of force at the point. Whenever you draw a line of force *put an arrowhead on the line to indicate its direction.*

(*e*) **Lines of force of the earth's magnetic field.** The earth itself is a huge magnet. There is a field both inside and outside it. *The* *field is directed from south to north.* The lines point from south to north, for the north pole of a magnet always points towards the north. When you draw lines of force of the earth's magnetic field, the *arrow-heads must point towards the north.* Remember this. The lines of force of the earth's field in a region free from magnetic matter are parallel to one another. But if a magnet is placed in such a region, the lines are distorted by the field of the magnet. The lines that we get in such a case are the lines of the field formed by the superposition of the magnet's field on the uniform field of the earth at the place.

(*f*) **Magnetic axis.** The line joining the two poles of a magnet is called its *magnetic axis.*

(*g*) **Magnetic meridian.** The vertical plane through the axis of a freely suspended magnet is called the *magnetic meridian* at the place.

6-1.2. Plotting Compass. A plotting compass (Fig. 6.1) has a short pivoted magnetic needle which is free to rotate in a horizontal plane. It is enclosed in a non-magnetic case and has a glass cover. It is convenient to have the sides also made of glass. The ends of the needle are pointed. The north end is generally coloured. The line joining the two ends is taken as the magnetic axis of the needle. In a magnetic field, the needle will set itself tangential to the local line of force.

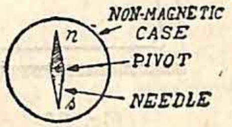


Fig 6.1

6-2. Experiment 24

To locate the poles of a given bar magnet

Theory. The regions, near the ends, where the attractive power is strongest are known as the poles of the magnet. For simplicity we treat them as points. The distance between the poles is called magnetic length. Since the pole are not situated at the ends, the magnetic length is less than the length of the magnet. The ratio of the magnetic length to the length of the magnet is nearly constant and its value is nealy 0·85. So we can write, $\frac{\text{magnetic length}}{\text{length of the magnet}}=0{\cdot}85$

Apparatus. A powerful long bar magnet; a small compass needle, a long thread; two long, hard brass pins; drawing board; four drawing pins and a piece of paper.

[Directions for experiment:

(1) Remove all the magnetic substances from the table. Near the table there should not be any magnetic substance.

(2) Fix the paper on the drawing board by pins and place the magnetic compass on the paper. After freely rotating the needle points north-south directions. Now stretch the thread above the needle and parallel to its axis by means of two long pins (Fig. 6.2) Fix the pins on the table in such a way that the board can move freely below the thread. The vertical plane in which the thread lie is the magnetic meridian.

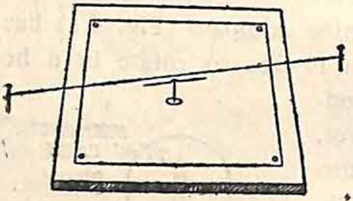


Fig. 6.2

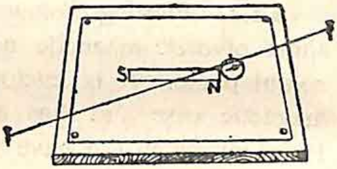


Fig. 6.3

(3) Remove the needle and place the magnet in the middle of the paper. Draw outline of the magnet by a pencil. Now place the needle very near to its north end. Slowly move the board until the axis of the needle become parallel to the thread (Fig. 6.3).

(4) Mark the two ends of the needle by two dots (L , L′). The line you get by joining the two dots gives you the line of foree of the experimental bar magnet in the magnetic meridian at that place.

(5) Remove the needle and place it in another position of the same end. Rotate the board until the thread just come parallel to the axis of the needle. Mark the points L_2, L_2' at the ends of the needle by pencil. Find another pair of points L_3, L_3' at different position.

(6) By same procedure find three pair of points on the lines of force at the other end of the magnet.

(7) Join each pair of points and extend the line towards the magnet. They will meet at a point inside the magnet. This point is one of the poles. Similarly join the other three pair each at the other

end and find the pole at the other end. [Choose the points in such a way that there is a symmetry. Take two pairs at the corners and one on the axis.] Ascertain the poles and give arrow in the proper direction.

(8) Measure the length of the magnet and magnetic length thrice and find the ratio of magetic length and length of the magnet. It will be nearly 0·85.]

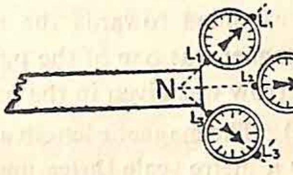


Fig. 6.4

Observations and Calculations

No. of obs.	Length of the magnet in cm.	Mean length L	Magnetic length in cm.	Mean Magnetic length l	Value of l/L
1.	....		....		
2.	....	.... cm.	....	.... cm.	....
3.	....		....		

Result. The ratio of the magnetic length to the length of the given magnet = ···

Method followed.

(1) Removing all the magnetic substances from the table, the paper was fixed on the drawing board.

(2) The compass needle was placed on the middle of the paper and the long thread was stretched above the needle and parallel to its axis by means of two long brass pins fixed on the table in such a way that the board can move freely below the thread.

(3) The needle was removed and the bar magnet was placed at the middle of the paper. The outline was drawn by a pancil. The needle was placed very near at one of its ends and the board was rotated until the axis of the needle was parallel to the thread. The ends of the needle were marked by a pencil.

(4) The needle was removed and placed at different position. The board was again rotated until the axis of the needle was parallel to the thread. The ends of the needle were marked by pencil. A third pair of points similarly found.

(5) The same procedure were adopted to find the three pair of points at the other end.

(6) Each pair of points at the same end were joined and the lines were extended towards the magnet. Their intersecting point within the magnet was one of the poles. Similarly the other pole was located. The arrow was given in the proper direction on the lines of force.

(7) The magnetic length and the length of the magnet were measured by a metre scale thrice and their ratio determined.

Precautions.

(1) The bar magnet should be long. The induction of one pole will not affect the other pole if the magnet is a long one.

(2) If the magnet is thick and short the line will not meet at a point.

(3) The lines of force are straight near the magnet and bends at a distance. So the needle should be placed very near the magnet.

Oral questions: (1) What is magnetic meridian? (2) What is the harm if the magnet is not placed in the magnetic meridian? (3) What will be the advantage if there is no magnetic field due to earth? (4) What is pole? (5) Can you isolate a single pole?

Ans. (1) See Sec. 6-1. (2) Due to earth's magnetic field the lines of force of the magnet will be changed. The lines will not meet at a point within the magnet. (3) We are not to bring the needle in the magnetic meridian. (4) Sec Sec. 6-1 (5) Poles cannot be isolated.

6-3.1. Experiment 25

Mapping the lines of force of a bar magnet, the north pole pointing north and to locate the neutral points

Theory. The lines of force of the earth's magnetic field at a place free from magnetic substances, are parallel. But if a magnet is placed in such a region, the field of the magnet is superposed on the earth's field, distorting the latter. The lines of force of the combined field can be plotted with a plotting compass. The new pattern of the lines of force is determined by the orientation of the magnet relative to the the earth. In this combined field, there are two points where the intensity due to earth's field is equal and opposite to the intensity due to magnet, i.e. the resultant intensity is zero. These points are called neutral points.

Apparatus. Drawing board; a large sheet of drawing paper; four *brass* drawing pins (the board or the pins must not have any iron nails); a weak, permanent bar magnet (with the north pole marked); a plotting compass.

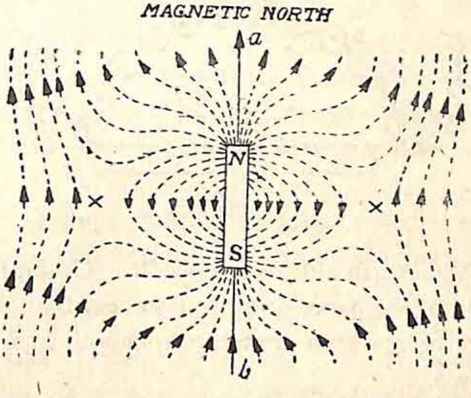


Fig. 6.4

[**Directions for the experiment.**

(1) Fix the drawing paper on the drawing board. Draw a line *ab* (Fig. 6.4) along the middle of the paper.

(2) Place the compass on the line. Turn the drawing board till the line is parallel to the magnetic axis of the needle. Check the parallelism as best as you can by shifting the needle from one end of the line to the other. When they are parallel, the line marks the magnetic north-and-south. (The line will be in the magnetic meridian.)

[If a long magnetic needle is available, it can be used with greater profit to bring the line *ab* in the magnetic meridian.].

(3) Mark the boundary of the drawing board on the table with a piece of chalk. If the board is accidentally displaced you can restore it to its correct position. The line *ab* will then be back to the magnetic meridian.

(4) Remove the compass. Place the bar magnet on the line *ab* near the middle of the paper with its north pole pointing north. Take the longitudinal middle line of the magnet as its axis. See that this line lies above the line *ab*.

(5) Draw the boundry of the magnet with a sharp pencil. (In doing so, see that the magnet or the board is not displaced in any way.)

(6) Keep the compass near (but not too near) the north end of the magnet. Mark the positions of the two ends of the needle by two sharp dots A and B (Fig. 6.5).

(7) Move the compass so that the south end of the needle is over B (where the north end previously was). Lightly tap the compass to make sure that the needle has not got stuck. Mark the position C of the north end of the needle.

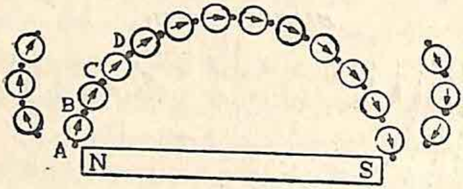


Fig. 6.5

(8) Move the compass in this way. At each step, mark the new position of the north end of the needle. Go on in this way till you reach the end of the paper or a position near the south end of the magnet. Join the points by a continuous smooth line. You have drawn a line of force.

(9) Start from some other point (Fig. 6.5) near the north pole. Draw the line of force through it in the same way (that is, as described in (6), (7) and (8) above.)

(10) In this way draw at least four lines of force from near the north end, and another four from near the south end. (Do so from similar points near the two ends).

(11) Slowly move the compass along a line perpendicular to the axis of the bar magnet through its middle point. After you have gone some distance you will find that the compass needle suddenly swings through 180°. A little before this position has been reached you will find a position along the perpendicular line where the needle shows no directional effort. It does not tend to turn in any particular direction and remains in any position in which you keep it. The central position of the small region over which this occurs is called the **neutral point.** Here the earth's horizontal field has been neutralized by that of the magnet. There being no magnetic field, the needle shows no tendency to turn. Find the position of the neutral point carefully and mark it with a cross. On the other side of the magnet there will be another neutral point at the same distance. Find and mark that one also with a cross (Fig. 6.4).

(12) On the eastern and western sides of each neutral point the compass needle points in opposite directions. Draw at least one line of force on each side (east and west) of each neutral point. (Four lines for the two neutral points.) Note that each pair of lines has

opposite directions. The outer one is from south to north; the inner one is from north to south.

[To get a symmetrical pattern, you may follow the suggestion in italics under 'Remarks' which follows.]

(13) Mark the directions of all the lines of force you draw. Try to draw as many of them as time would permit. Select symmetrical positions to draw them. When there are enough lines the pattern looks as in Fig. 6.4.]

Result. The pattern of the lines of force of a bar magnet with its north pole pointing north has been shown on the attached sheet.

Method followed.

(1) The drawing paper was fixed to the drawing board with non-magnetic pins. A straight line *ab* was drawn down the middle of the paper. The needle was placed on the line. The board was turned until the line *ab* become parallel to the needle, *ab* was then in the magnetic meridian.

(2) The boundary of the board was marked on the table with a piece of chalk. This would enable restoring the line *ab* to the magnetic meridian if the board was accidentally displaced.

(3) The bar magnet was placed in the middle of the paper with its north pole pointing north and its axis (the longitudinal middle line) on the line *ab*.

(4) The boundary of the magnet was marked on the paper with a sharp pencil. This would enable restoring the magnet to its right position if by any chance it was displaced.

(5) A number of lines of force were drawn from near each end of the magnet with the help of the compass needle.

(6) The compass was moved along the line perpendicular to the magnet axis passing through the centre of the magnet till the *neutral point* was reached. Lines of force were drawn on opposite sides of each of the two neutral points.

Précautions.

(1) There should be no magnetic material, other magnet or strong electric current near the working table. It would disturb the field being mapped.

(2) After the magnet has been placed in the magnetic meridian, it must not be disturbed. Though boundaries have been drawn, resetting may not be exact.

Remarks. If the line *ab* is not exactly in the magnetic merdian, the pattern will not be as symmetrical as shown in Fig. 6.4. This applies also to the next experiment (Fig. 6.6).

To give your Pattern an elegant and symmetrical look, mark equidistant points along the perpendicular line (through the centre of the magnet). These may be 2 cm apart. Draw lines of force through them.

Oral questions. (1) Whose magnetic field are you drawing?

(2) How can a line of force be drawn with the help of a compass needle?

(3) Explain the terms *lines of force, magnetic meridian, magnetic axis.*

(4) What is meant by the 'direction of a line of force'? How is it shown?

(5) What is the direction of a line of force of the earth's field?

(6) What is a *neutral point*? In which direction does a compass needle point at a neutral point?

(7) Why have you been advised to use a 'weak' bar magnet?

Ans. (1) The combined field of the magnet and the earth. (The field of the bar magnet as modified by the earth's field.) (2) See items (6) (7) and (8) under 'Directions for the experiment'. (3) See items (d), (f) and (g) of Section 6-1.1.(4) and (5) See items (d) and (e) of Section 6-1.(6) When two magnetic fields are superposed the intensity of one of the fields may be equal and opposite to that of the other at a point. Such a point is called a neutral point. Since there is no resultant magnetic field at the point, a small magnetic needle will have no tendency to turn in any particular direction at the point. It will stay in whatever direction it is kept. (7) If the bar magnet were strong, the neutral points might lie outside the paper. In that case their positions cannot be determined and shown. An important characteristic of the combined field will remain unrepresented.

6-3.2. Experiment 26

Mapping the lines of force of a bar magnet, north pole pointing south and to locate the neutral points.

Theory, Apparatus, Directions for the experiment are the same as for the last experiment, except that the bar magnet must be placed with its north pole pointing south.

The pattern of the lines of force will be as shown in Fig. 6.6. The neutral points will lie on the magnetic axis. These may be determined by moving the compass along the magnetic axis. Past the neutral point the needle will swing in the opposite direction.

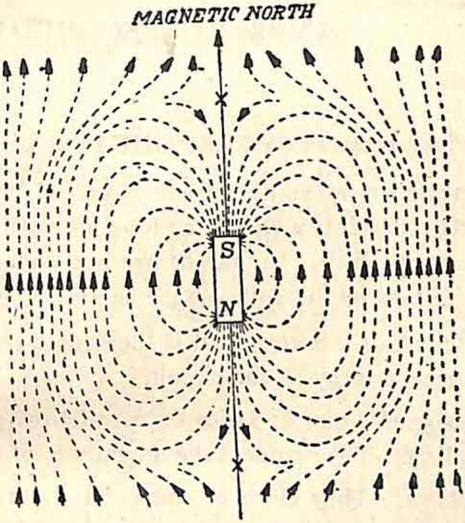


Fig. 6.6

See also the 'Remarks' in the last experiment.

Oral questions and Answers are as in the last experiment.

CHAPTER 7

CURRENT ELECTRICITY.

7-1. Introductory remarks on ELECTRICAL experiments.

In all experiments on current electricity you will build an 'electric circuit'. An **electric circuit** is a closed, conducting path through which an electric current can flow. So far as we are concerned here, an electrical circuit will have the following essential components:

(*i*) *An electric cell or a battery.* It is the source of electric power and supplies electrical energy to the circuit.

(*ii*) *One or more resistors* in series or parallel (or partly in series and partly in parallel). They control the magnitude of the current.

(*iii*) *Key or Keys.* They close or open the circuit (that is, start or stop the current flow). There are keys for reversing the direction of current through a part or whole of the external circuit. External circuit means the part of the circuit outside the cell or battery.

(*iv*) *Various measuring instruments.*

Circuit diagram. An electric circuit is always represented by a line diagram, called the *circuit diagram*. In it, the different components are represented by *symbols* which are well known.

Our first task will be to get a working acquaintance with the essential components of a circuit and the symbols by which they are represented, as well as the components themselves.

7-2. The electric cell. Its symbol has been shown in Fig. 7.1(*a*). The longer vertical line is the positive terminal of the cell. The shorter and thicker one is the negative one. The side lines represent conducting wires by which the cell is connected to other electrical componets of the circuit. The lines are treated as having no resistance.

In the laboratory you may use three kinds of cells, namely, (*i*) the Daniell cell, (*ii*) the Leclanchè cell and (*iii*) the lead-acid storage cell. The first two are primary cells; the last one is a secondary cell (or accumulator). In both kinds of cells, chemical energy is transformed into electrical energy. When one of the chemical reactants (the cathode or the electrolyte) is exhausted, a primary cell will no longer work. But a secondary cell can be revived by sending an opposite current through it (opposite in direction to the current the cell itself gives). The old reactants are formed again.

Brief descriptions of the cells are given below.

(*i*) **The Daniell cell.** Fig. 7.1(*b*) shows its construction. Its emf (electromotive force) may be taken as 1.08 volts. The internal resistance of the cell is a few ohms, and depends upon the size and construction. It can give a weak, practically constant current for a long time. After the work is over it is best to dismantle the cell. At least remove the zine rod and along with it the porous pot. The zinc terminal is negative.

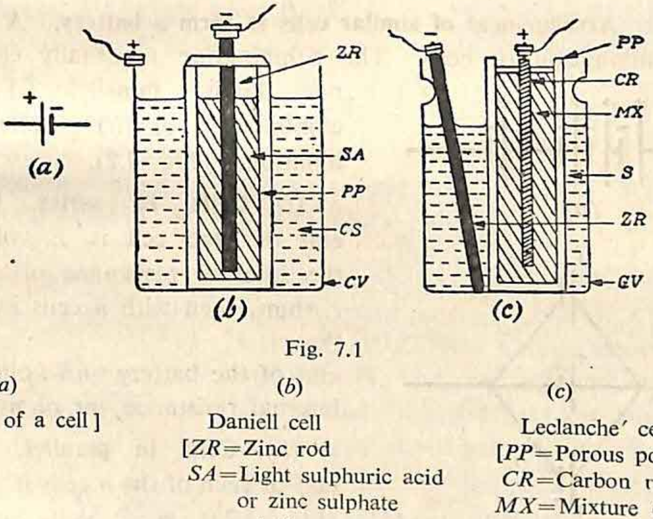


Fig. 7.1

(*a*)
[Symbol of a cell]

(*b*)
Daniell cell
[ZR=Zinc rod
SA=Light sulphuric acid or zinc sulphate solution
PP=Porous pot
CS=Saturated copper sulphate solution
CV=Copper vessel]

(*c*)
Leclanche′ cell
[PP=Porous pot
CR=Carbon rod
MX=Mixture of MnO_2 and carbon powder
S=NH_4Cl solution
ZR=Zinc rod
GV=Glass vessel]

(*ii*) **The Leclanche′ cell.** Fig. 7.1(*c*) shows its construction. Its emf is about 1.45 volts and the internal resistance is a few ohms. In delivering a continuous current, its voltage slowly falls and the current diminishes. The fall is quicker the stronger the current. The reason lies in the inability of MnO_2 in reducing polarization at once; it takes a little time. So the cell is suitable for the kinds of work which require a current for short durations. It can be used with the metre bridge or the P.O. box. A prepared cell can be kept for a long time without damage. The zinc terminal is negative.

(*iii*) **The lead-acid storage cell (or lead accumulator).** As we have said earlier, it is a secondary cell. Its positive and negative terminals are respectively marked + and −. In some cases the positive terminal is coloured red and the negative terminal black. The emf is usually taken as 2 volts. The cell has a very low internal reistance. So, if it is 'short circuited' ('that is, if the two terminals are connected together by a very low resistance) a very large current will flow through the cell. This will damage the cell beyond repair. You must, therefore, always keep a resistance of at least one or two ohms in series with it in the external circuit.

7-2.1. Arrangement of similar cells to form a battery. A *battery* is a combination of cells. The combination is usually either of two kinds, namely, (*i*) series combination or (*ii*) parallel combination. (Fig. 7.2).

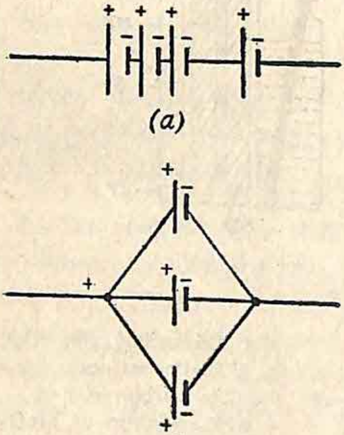


Fig. 7.2 (a=Symbol of series combination of cells; b=parallel combination)

(*i*) **Cells in series.** If the emf of each cell is E volts and the internal resistance of each is r ohms, then with n cells in series, the

emf of the battery $= nE$ volts, and
internal resistance $= nr$ ohms.

(*ii*) **Cells in parallel.** If the emf of each of the n cells in parallel (Fig. 7.2*b*) is E volts and the internal resistance is r ohms each, then

emf of the battery $= E$ volts;
internal resistance $= r/n$ ohms.

When we require a higher voltage in a circuit than a single cell can give, we use cells in series. When we want a higher current than one cell is capable of giving, we use cells in parallel.

7-3. Different kinds of Keys. A 'Key' is a simple device by means of which the current in a circuit can be established or discontinued at will. (It can be compared with the 'switch' in a household circuit.) There are also 'reversing keys' which reverse the current in the circuit or in a part thereof.

(*i*) **Plug Key.** Fig. 7.3(*a*) shows its symbol and Fig. 7.3(*b*), its construction. The actual key consists of two brass pieces (B) separated by a small gap and fixed on a nonconducting base (N). Each piece has a binding screw *T* attached to it. The circuit is severed somewhere and the two ends of it are connected to these two binding screws. Between the two brass blocks there is a tapering socket S. A brass plug P of the same size fits into the socket. When the plug is put in the socket the circuit is completed and current flows. When it is taken out, the circuit is broken and the current stops. When you insert or take out the plug, give it a little twist.

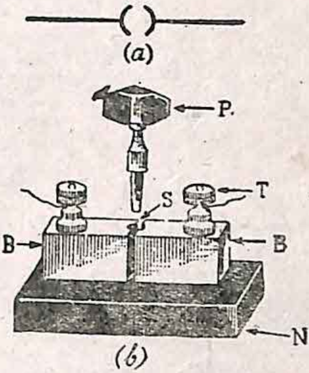


Fig. 7.3 (*a*=Symbol of plug key; *b*=construction of plug key)

(*ii*) **Tapping Key.** Fig. 7.4 (*a*) shows the symbol and Fig. 7.4 (*b*) the construction of a tapping key. It has two binding screws A and C fixed upon a nonconducting base N, and also a metal stud B. B and C are connected by an insulated wire underneath the base. A has a springy metal strip S attached to it. At the other end of S there is a nonconducting stud K above it, and a metal one below it. Two sides of the circuit are connected to A and C. When K is pressed A and C are metallically connected and current flows through the circuit. As soon as K is released the circuit breaks.

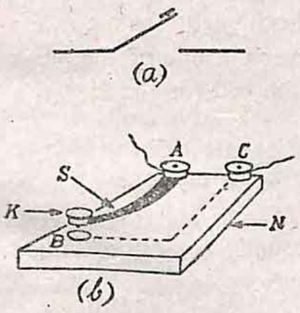


Fig. 7.4. (*a*=Symbol and *b*=structure of tapping key)

The tapping key is suitable for use in a circuit which should remain open most of the time, and require to be closed occasionally.

(*iii*) **Reversing Key.** Fig. 7.5 (*a*) shows the symbol of a reversing key. In Fig. 7.5 (*b*) a very common form of such key is shown. (There are various forms.) In it, four thick pieces of brass are fixed on a nonconducting base, each a little separated from the others, as in a plug key. Each block has a binding screw. Between any two neighbouring blocks there is a conical socket, and two plugs to fit into sockets. The positive (+) and negative (−) terminals of the battery are joined to any pair of diagonally opposite screws (B+, B−). To the other pair (C_1, C_2) are joined the two ends of the circuit.

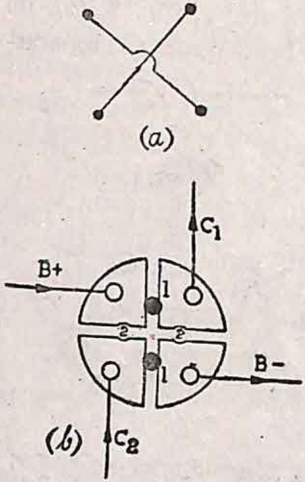


Fig. 7.5. (*a*=Symbol and *b*=structure of reversing key)

If the plugs are in the sockets 1, 1, the current from the battery comes through B+, and enters the circuit through C_1. It returns through C_2 and B−back to the battery. If the plugs are in the sockets 2, 2, the current passes from B+ to C_2. In this case the direction of flow of current through the circuit is opposite to that in the previous case. This is how we use the reversing key.

When you use a reversing key, take out both plugs from sockets 1, 1 and then insert them in sockets 2, 2. Never put one of the plugs in 1 and one in 2. This may 'short circuit' the cell (or the battery). This will be injurious for the latter.

Insert or remove the plugs with the usual twisting motion.

7-4. Resistances. Electrical resistances usually consist of coiled pieces of insulated wire placed in a suitable cover.

(*i*) **Fixed resistance.** Fig. 7.6(*a*) shows the symbol of a *fixed* resistance. The actual resistor may be of various types. One type is shown in Fig. 7.6(*b*). An insulated wire of appropriate length is folded on itself, and this folded wire is wound round a wooden bobbin. It is then covered with wax. The bobbin is placed in a nonconducting case. The ends of the wire are connected to two binding screws on the cover. The value of the resistance is generally imprinted on the cover.

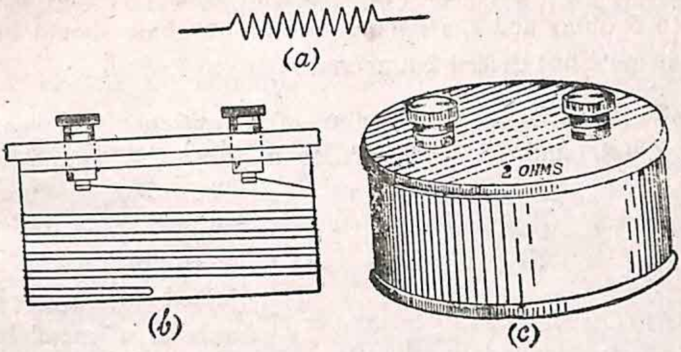


Fig. 7.6 (a=Symbol and b, c=structure of a fixed resistance)

Such resistors cannot carry strong currents. Strong currents heat them and the resistance increases with temperature. Fine wires may be melted by a strong current.

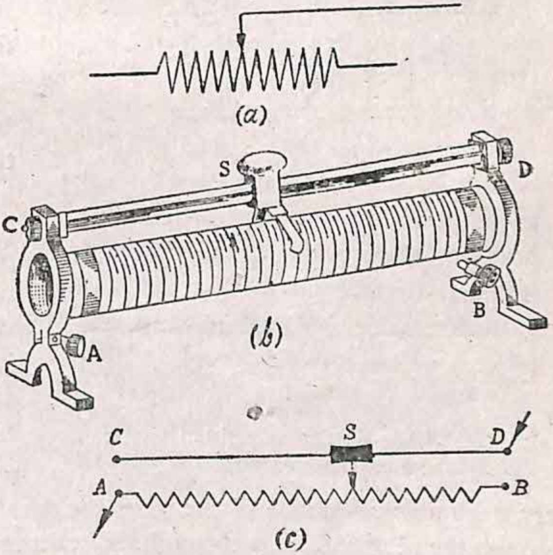


Fig. 7.7 (a=Symbol of a rheostat. b=its construction: c=mode of action)

(*ii*) **Rheostats.** A rheostat is a variable resistance, whose value can be changed within the limits of its construction. Fig. 7.7(a) shows the symbol of a rheostat and 7.7(b) its construction. In the type pictured here, a bare manganin or eureka wire is wound along a spiral groove in a porcelain tube. Any desired portion of the wire can be included in the circuit with the help of a sliding contact S (Fig. 7.7b). If the circuit is connected to the terminals A and D (Fig. 7.7c) the AS part of the rheostat is included in the circuit.

The maximum value of the resistance and the maximum current it can bear (without appreciable heating) are written on the rheostat. A "5-ohm, 2 amp" rheostat means that the resistance can be varied from 0 to 5 ohms and the maximum current which should be sent through it must not exceed 2 amperes.

(*iii*) **Resistance box.** The symbol of a resistance box is shown in Fig. 7.8(*a*), and its construction in Fig. 7.8(*b*) and 7.8(*c*). The box contains a number of resistance coils of fixed value joined in series by a number of metal blocks M. There is a small gap G and a tapering socket (as in a plug key) between neighbouring blocks. There are plugs fitting each socket.

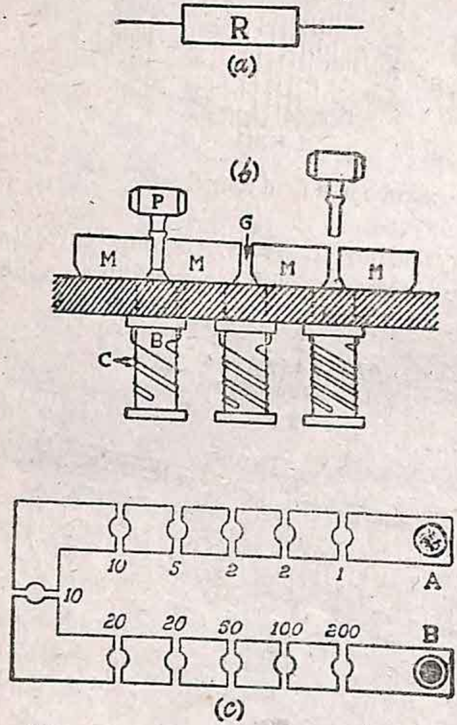


Fig. 7.8 (*a*=Symbol of resistance box; *b* and *c*=structure)

When a resistance box is connected by its terminals to a circuit and any of the plugs is taken out, the current passes through the resistance coil below the plug. When a plug is in position, the resistance below it is shunted (or short circuited) by the plug. Because of the very negligible resistance of the plug, the whole of the current passes through the plug and none through the resistance.

The resistance of the coil below a plug is written near the corresponding gap on the lid of the box (Fig. 7.8*c*). There are two binding screws at the two ends of the box. The circuit is connected through them to the box. Fig. 7.8*c* represents the lid of a resistance box. The values of the resistances contained in the box are such that you can get any value from 1 ohm to 420 ohms. You can remove as many plugs as you like. Give the plug a twist while taking it out or putting it in. The plugs which are kept in their sockets must be tight.

In a rheostat, the variation of resistance is continuous; but in a resistance box it can be in steps only. The smallest step corresponds to the smallest resistance in the coil. Besides, a rheostat is constructed to carry heavy currents (0.5 ampere or more). But a resistance box should not be made to carry a current of more than 20 milliamperes or so.

7-5. Galvanometer. A galvanometer is used for detecting small electric currents. It is a very delicate instrument. Its appearance and construction differ widely. You will generally be given 'Moving-coil Table Galvanometers' for use. Depending on construction they can detect currents of about 1 to 10 microamperes. Smaller currents will go undetected by the instrument.

In a 'moving-coil' galvanometer, a rectangular coil of many turns of fine insulated wire is placed in the strong magnetic field of a permanent magnet. When a current passes through the coil, it tends to set itself perpendicular to the field. The tendency to turn is opposed by delicate spiral springs. The result is that the coil undergoes an angular deflection depending on the current, the stiffness of the springs and the strength of the magnetic field. The angular deflection of the coil is indicated by the motion (on a scale) of a pointer attached to the coil. If the direction of flow of current in the coil is reversed, the coil turns in the opposite direction, and so does the pointer. The zero of the scale is in its centre. (These are often called *centre-zero* instruments.) The advantage is that you can say from the motion of the pointer that the position of no current through the galvanometer has been crossed.

Galvanometer shunt. Since the galvanometer is a very delicate instrument you must avoid situations in which a large current can pass through it. (Even a milliampere is considered too strong for a galvanometer.) As you do not know what current will initially pass through when it is first connected to a circuit, *you should always have a low resistance connected across its terminals as a shunt.* Such a low resistance may be constructed by a few turns of *very fine* insulated wire. The shunt resistance must be much smaller than the galvanometer resistance. It will be conveninent also to have a plug key *in series* with the shunt. When you don't want the shunt you can just take out the plug of the key.

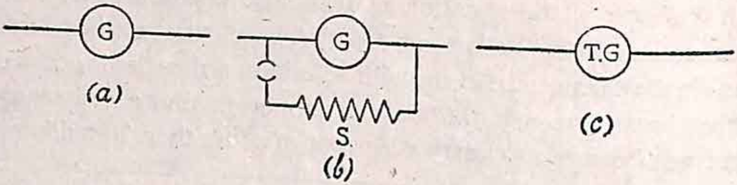


Fig. 7.9 (*a*=Symbol of galvanometer; *b*=shunted galvanometer; *c*=tangent galvanometer)

Fig. 7.9(*a*) shows the symbol of a galvanometer, and Fig. 7.9(*b*) the symbol of a shunted galvanometer provided with a key. G is the galvanometer and S the shunt.

The symbol of a tangent galvanometer is shown in Fig. 7.9 (*c*).

7-6. Ammeter. An ammeter measures the current in a circuit or a branch of it directly in amperes. The ammeter is connected in series with the conductor in which the current is to be measured. An ammeter should have *a very low resistance* so that its insertion in the circuit does not appreciably alter the current in the circuit.

Generally, an ammeter is a moving coil galvanometer shunted by a low resistance. The scale of an ammeter is an essential part of it, and is graduated in amperes. Since the direction of rotation of a coil depends on the direction of the current through it, the terminals of an ammeter are marked + (positive) and − (negative). The positive terminal must always be connected to the positive side of the circuit. This will ensure that the ammeter needle moves over the scale in the right direction. Otherwise, the needle will move in the opposite direction (beyond the zero end of the scale). Wrong connection will damage the needle. In using an ammeter you must make sure that (*i*) it is connected in series and (*ii*) the positive terminal is connected to the positive side of the circuit. (To understand which is the positive side of the circuit, move along the circuit from the positive pole of the battery. The end that you reach first is the positive end.)

The symbol for an ammeter is shown in Fig. 7.10(*a*).

7-7. Voltmeter. A voltmeter is used for measuring the potential difference between two points of a circuit directly in volts. Fig. 7.10(b) shows its symbol. In principle, a voltmeter is a galvanometer with a high resistance in series with it. It is connected to the points between which the potential difference is to be measured. So the connection here is in parallel with the concerned part of the circuit. It acts as a shunt to that part. Its resistance being high, it draws very little current from the circuit.

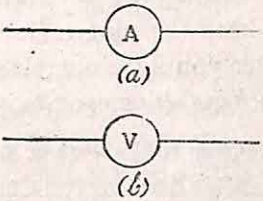


Fig. 7.10
(a=Symbol of ammeter: b=symbol of voltmeter)

The most commonly used voltmeter is the moving coil voltmeter. It is, in principle, a moving coil galvanometer with a high resistance in series with the coil. The resistance is placed within the instrument. The scale is an essential part of it and is graduated in volts. As in the ammeter, the terminals of a voltmeter are also marked + and −. The + terminal must be connected to the positive side of the circuit.

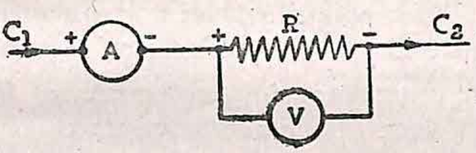


Fig. 7.11 (Series connexion of ammeter A in circuit C_1C_2, and parallel connexion of voltmeter V across resistor R)

Fig. 7.11 shows how an ammeter and a voltmeter must be connected to a circuit.

7-8. Building a circuit. A circuit will always contain a cell or a battery of two or more cells. The cell or the battery causes electric current to flow through the circuit. The necessary resistances and instruments are connected together, as required, by short, insulated copper wires. The terminal of a resistance or instrument that you reach first as you move along the circuit from the positive pole of the cell, is the positive end of the resistance or the instrument. In connecting ammeters and voltmeters, trace the positive end in this way.

In every experiment the circuit diagram is given. When using connecting wires remove the insulation from about 3 cm of both ends of the wire. You may find the ends bared by previous use. If the bare ends appear greasy or coated, clean the ends with sand paper. Bend an end into a U and connect it to the binding screw.

Tighten the screw enough so that the contact is good and not loose. Looseness can be tested by giving the wire a slight pull. *All connections should be tested in this way.*

Use a plug key next to the cell or battery. Keep it open (that is, keep the plug removed) so long as you do not require a current. After you have completed building the circuit, *get it checked by your teacher*. *If he permits*, put the plug in position and *start work*.

Note that when a number of resistances are to be connected in series, it does not matter which one you place nearest to the cell, or towards its positive or negative pole. Suppose a resistance of 10 ohms and one of 100 ohms are to be connected in series with the cell in the circuit. You can place any one of them near the positive pole or the negative pole, or one on either side of the cell. (Many of you may have misconceptions in this regard. Hence the advice.) All that matters is that the appliances must be in series. Their position relative to one another is immaterial.

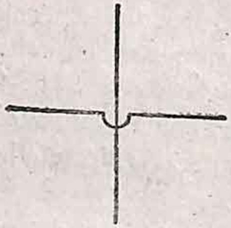


Fig. 7.12 (Symbol of one wire crossing another without touching)

The connecting wires are represented by straight lines. Their resistances are entirely ignored. You need not arrange the connecting wires exactly as they are shown in a circuit diagram. A long line does not necessarily mean a long wire or a short line, a short wire. They merely show which is connected to which. Use lengths of wire as are convenient and try to give the circuit a neat look. The reading instruments must be so placed that you can read them easily. Resistances which are to be adjusted should be so placed that you feel no obstruction in handling them. A circuit diagram *does not* mean that the relative positions of the components should be as in the diagram. You can change the positions according to your convenience.

Sometimes it is necessary to show that a connecting wire crosses another without metallic connection between them. On a circuit diagram, this is symbolically represented as in Fig. 7.12.

Don't work mechanically. Try to understand. *Use your brain.* Things are really simple.

7-9. Experiment 27

To verify Ohm's law using an ammeter and a voltmeter

Theory. Ohm's law states that if physical conditions are unaltered, the current (I) through a conductor will be proportional to the potential difference (V) between its ends. That is, $\frac{V}{I}$ = constant. Its truth can be verified by measuring the current through a conductor with an ammeter and the potential difference between its terminals with a voltmeter. For different values of the current the ratio of the two quantities should remain constant.

Apparatus. A battery of two storage cells in series (B; Fig. 7.13); plug key (K); rheostat (Rh; say, one of 5-ohm, 3-ampere specification); ammeter (A; range 0→1.5 amp); an unknown resistance of about 4 ohms, made of relatively thick manganin or eureka wire; voltmeter (V; 0→5 volts); connecting wires.

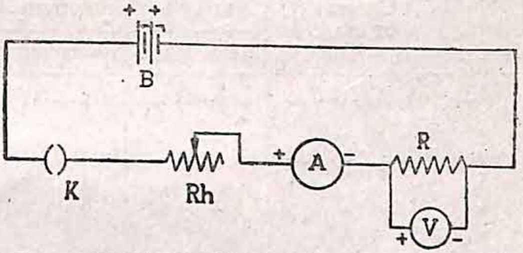


Fig. 7.13 (Circuit diagram for verifying Ohm's law using ammeter and voltmeter).

(Each electrical experiment requires instruments with ranges suitable for the purpose. In all the experiments we describe we shall state such ranges. But an institution may not have these ranges. In such a case, the teacher will advise the student on the range to use.)

[**Directions for the experiment.**

(1) Build a circuit as shown in Fig. 7.13. It will be of advantage if you read Sections 7-1 to 7-8 first and follow instructions. Don't put the plug in the key at first. The pointer must be on the zero mark in A and V. If they are not, point this out to the teacher. He may set them correctly.

If they cannot be set at zero, the reading will require a correction as in slide callipers or in a screw gauge. Note the zero errors and add or subtract them as necessary from the apparent readings.

(2) *Get the circuit checked by the teacher.* When he permits, put the plug in the key and start work.

(3) Include the full resistance of Rh in the circuit at first. The current in the ammeter will be the smallest in this case. The voltmeter reading will also be the lowest. Note their readings.

(4) Reduce the resistance in Rh a little. This will increase both *I* (current) and *V* (voltage). Note the new values.

(5) Take at least five sets of readings of *I* and *V* by changing the resistance of Rh. Firsty by decreasing and then by increasing Rh. Close the circuit only when you want to take the readings. At other times keep it open (that is, plug removed).

(6) Take out the plug. Remove the battery connection.]

Observations and Calculations

No. of obs.	Current (I) in amp.	Potential difference (v) in volt when current		Mean (V) in volt	Value of $\frac{V}{I}$ in ohm.
		increasing	decreasing		
1.	....	....	....	....	....
2.					
3.					
:					
etc.					

(Express the ratio V/I in decimals)

Conclusion. From the table it is seen that the ratio V/I is constant (within limits of experimental error). This shows that they are proportional to each other. This verifies Ohm's law, which states that *I* is proportional to *V*.

(The resistance of the resistor to which the voltmeter is connected in series is $V/I=R$ ohms. It is the mean value of the ratio V/I as we can get from the table.)

Method followed.

(1) The circuit was built as in the circuit diagram. The plug key was left open. It was checked that the pointer of the ammeter and the voltmeter both read zero in this condition. The maximum resistance of the rheostat was included in the circuit.

(2) I got the circuit checked by the teacher. When he permitted I closed the circuit by putting the plug of the key in position. After

recording the readings of both the ammeter (I) and the voltmeter (V), the circuit was broken.

(3) The resistance in the rheostat was reduced a little. The circuit was closed, and the I-V readings were taken. The plug was again removed.

(4) Operation (3) was repeated to get altogether five sets of I-V readings, first by increasing and then by decreasing the current.

(5) The plug in the key was removed, and so also the battery connections.

Precautions.

(1) The physical conditions of the conductor must not change during the experiment. The most important physical condition in this case is the temperature. A large current may heat the conductor. This was guarded against. Care was taken not to use too strong a current as it may produce appreciable heating of the conductor.

(2) Current was allowed to flow for a while before taking the readings. This allowed the conductor to acquire temperature equilibrium.

Remarks.

(1) The experiment also gives the resistance $R(=V/I)$ of the conductor.

(2) Temperature rise of the conductor must be guarded against. Use of manganin or eureka wire is convenient. Its temperature coefficient of resistance is very low. To guard against much Joule heating, a relatively thick wire or small currents should be used.

(3) I and V may be read up to three significant digits by eye estimation. So the third digit in R will vary. The first two digits ought to remain constant.

(4) K, Rh, A and R are in series in the circuit. It does not matter what their relative positions are. The voltmeter must always be in parallel with R.

(5) The I-V or V-I graph will be a straight line passing through the origin ($I=0$, $V=0$). Draw such a graph to test the quality of your work.

A straight line graph through the origin means that the quantities plotted are proportional to each other.

Oral questions. (1) What is Ohm's law? What is meant by keeping physical conditions unaltered?

(2) What are storage cells (or accumulators)? What is the voltage of a lead-acid cell?

(3) What would be the advantage or disadvantage if you used Daniell cells in this experiment? Could you use Leclanche' cells?

(4) What is the action of a rheostat? Show which portion of its resistance has been included in the circuit.

(5) What is the use of an ammeter? What is its construction? What is its action?

(6) What are the use, construction and action of a voltmeter? Does it have a high or a low resistance?

(7) How are ammeters and voltmeters related to galvanometers?

(8) What is the resistance of the conductor you have been given?

Ans. (1) See 'Theory'. The most important physical condition in this case is the temperature. (The resistance of a bismuth wire depends on the magnetic field in which it may be placed. That of selenium depends on the amount of light falling on it. But the resistance of all conductors depends on temperature. So temperature is the most important physical condition in this case. Other physical conditions are special cases.) (2) See Section 7-2(c). Ordinarily 2 volts. (3) The voltage (=e.m.f. or p.d. expressed in volts) of a Daniell cell may be taken as 1 volt. If its internal resistance is taken as 10 ohms, it cannot give a current greater than 1/10 ampere. So an ammeter of low range will be necessary. If the given conductor has a high resistance, its terminal voltage may be relatively large. Supposing it had a resistance of 10 ohms. the current in the circuit would be $1/(10+10)$ amp, and the terminal voltage $1/20 \times 10 = 0{\cdot}5$ volt. This would also require a voltmeter of low range. So, if a Daniell cell were used, we would require low range ammeter and voltmeter and a conductor of relatively high resistance. A Leclanche cell is inconvenient. In continuous work, its e.m.f. slowly diminishes due to slow action of the depolarizer (MnO_2). So the current and voltage will not remain steady. (4) See Section 7-4(ii).(5) See Section 7-6. (6) See Section 7.7 (7). An ammeter is, in principle a galvanometer shunted by a low resistance. Its resistance is practically that of the shunt. A voltmeter is, in principle, a galvanometer with a high resistance in series. It has an overall high resistance. (8) The resistance of the conductor is the mean value of V/I.

7-10. Mechanical equivalent of heat

Under appropriate circumstances mechanical energy can be fully converted into heat energy. Let an amount W of mechanical work, on complete conversion into heat, produce an amount Q of heat. The ratio $W/Q=J$ is called the *mechanical equivalent of heat*. It is also called *Joule's equivalent*. The numerical value of J depends on the units in which W and Q are measured. In cgs units, W is in ergs and Q is in calories. In these units J is about equal to $4{\cdot}2 \times 10^7$ ergs per calorie. If work is measured in joules $J=4{\cdot}2$ joule/cal. J represents a fixed or *constant ratio* though its numerical value is dependent on units chosen to represent work and heat.

To determine J both mechanical work and heat have to be measured. As we are to measure J by electrical means, W will be the electrical work done.

7-10. Experiment 28

To determine J by electrical method

Theory. If the terminal potential difference of a resistor is V volts and the current through it is I amperes then, when the current flows for t seconds, the electrical work done is VIt. If the heat generated by this work is H calories, the ratio $VIt/H=J$ is a constant quantity. J is called Joule's equivalent or mechanical equivalent of heat and is expressed as 'joules per calorie'. Let the calorimeter used for measuring the heat have a water equivalent of W grams and let it contain m grams of water. If the heat H calories raises the temperature of the calorimeter and contents from T_1 °C to T_2 °C, then the heat $H=(W+m)(T_2-T_1)$ cal.

$$\therefore \quad J=\frac{V(\text{volts})\times I(\text{amp})\times t(\text{sec})}{(W+m)(T_2-T_1)\text{ cal}}=\frac{VIt}{(W+m)(T_2-T_1)}\,\frac{\text{joules}}{\text{calorie}}$$

Apparatus. Joule's calorimeter (JC); thermometer (T) (0°→50°C range; preferably divided into fifth of a degree); ammeter (A) (0→1·5 amp); voltmeter (V) (0→10 volts); plug key (K); stop clock; common balance with weight box; a 6-volt storage battery (preferably as used in motor cars). (Fig. 7.15.)

Description of Joule's Calorimeter.

Joule's calorimeter (JC; Fig. 7.14) is an ordinary calorimeter fitted with a wooden lid (L) on its container. The lid has two holes in it, one for a thermometer (T) and the other for the stirrer (S). There is a heating coil (NW) of nichrome wire inside the calorimeter. It has two leads (CW) of thick copper wire. Neither CW nor NW touches the calorimeter. The heating coil should have a resistance of about 4-6 ohms. The free ends of CW are connected to two binding screws BS on the lid. The battery circuit and the voltmeter are connected to the heating coil through

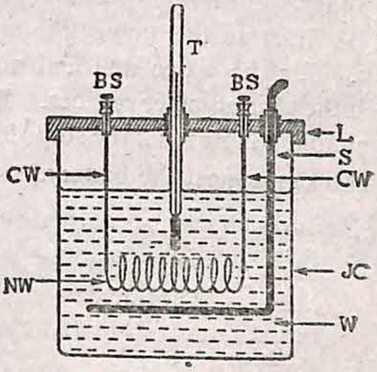


Fig. 7.14 (Joule's calorimeter)

these binding screws. The heating coil and the thermometer bulb are fully immersed in the water of the calorimeter.

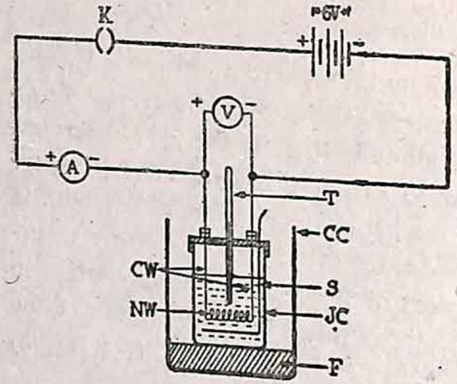


Fig. 7.15 (Circuit diagram for determining J)

[Directions for the experiment.

(1) Weigh the calorimeter and stirrer.

(2) Weigh it again with enough water to submerge the heating coil and the thermometer bulb.

(3) Build a circuit as shown in Fig. 7.15. Put the calorimeter in its container (CC).

(4) Get your circuit checked by the teacher. If he permits, begin work. Take the initial reading T_1 of the thermometer to tenths of a degree by eye estimation. Check the ammeter and voltmeter for zero error.

(5) Insert the plug in the key K and at the same time start the stop clock. Take the readings I of the ammeter and V of the voltmeter. Stir the water continuously.

(6) Allow the current to flow until the temperature rises by 8 to 10 degrees. Note if I and V have the same values as at the start. (If they differ, inform the teacher and use the mean values.)

(7) Take off the plug of the key K and at the same time stop the clock. Stir the water well and note the maximum temperature T_2 which the thermometer reaches. Read T_2 to tenths of a degree by eye estimation. Note from the stop clock how long the current has flowed.

(8) Disconnect the battery.]

Observations.

Mass of calorimeter + stirrer = ...g (m_1)
Mass of calorimeter + stirrer + water = ...g (m_2)
Initial temperature of water = ...°C(T_1)
Current = ...amp (I)
Potential difference = ...volts (V)
Maximum final temperature of water = ...°C (T_2)
Time of flow of current = ...seconds (t)

Calculations and Result.

Electrical work done $= VIT$ joules

Heat developed $= H = VIt/J$ calories $= \ldots/J$ cal (A)

Mass of water $(= m_2 - m_1 = m\ g) = \ldots$grams

Heat taken by water $= m(T_2 - T_1)$ cal. (B)

Specific heat of material of calorimeter $(s) = \ldots$ (given)

Heat taken by calorimeter and stirrer $= m_1s(T_2 - T_1) = \ldots$cal (C)

$(m_1s = W$ is the water equivalent of the calorimeter.)

If heat loss from the calorimeter is ignored, we shall have A=B+C.

$$\therefore\ J = \frac{VIt}{(m_1s+m)(T_2-T_1)} = \frac{\cdots\ \text{joules}}{\ldots\ \text{calories}} = \ldots\text{joules/cal}$$

Method followed.

(1) The calorimeter with stirrer was weighed. Enough water was taken in the calorimeter to submerge the heating coil and the blub of the thermometer. The calorimeter with the stirrer and water was weighed.

(2) The circuit as shown in the diagram was built. It was checked by the teacher. The ammeter and the voltmeter did not have any zero error.

(3) With the teacher's permission I started work. The initial temperature T_1 of the calorimeter water was carefully noted. The current and the stop clock were started simultaneously. The current I and the voltage V were noted.

(4) The water was stirred continuously. The temperature of water was allowed to rise by about 10 degrees. The values of I and V were checked to see if they had remained constant. (They was constant.)

(5) The plug of the key K was removed, breaking the circuit. The stop clock was stopped at the same time. The water was stirred and the maximum temperature T_2 reached by the water was noted. The time of flow of current was noted from the stop clock.

Precautions.

(1) The water must be continuously stirred.

(2) The thermometer bulb must not touch the heating coil.

(3) Constancy of the current and voltage should be checked.

Remarks. In this experiment, both the resistance of the heating coil and the voltage of the battery should be a little high. In the arrangement described, we shall have a resistance 4-6 ohms, and a voltage of 6(V). The current will be about 1 ampere. Electrical energy will be consumed at the rate of 6V × 1A = 6W (watts) per second. This will develop heat at the rate of about $6/4{\cdot}2 = 1{\cdot}4$ cal per second. If there are only 100 grams of water, it will take about 12 minutes for the temperature to rise by 10°C. The longer the calorimeter temperature remains above the room temperature, the more the heat will lose. As we are ignoring the heat loss, the value of J will be too high.

Oral Questions. (1) What is meant by the mechanical equivalent of heat? On what does it depend?

(2) Where is work being done in this experiment? Who is doing this work?

(3) Define the volt, the ampere and the coulomb.

(4) What is the resistance of your heating coil?

(5) If heat loss from the calorimeter were taken into account, how will the value of J change?

(6) How does heat loss from the calorimeter takes place?

Answers. (1) Mechanical or electrical energy can be fully converted into heat. If an amount W of mechanical or electrical energy is fully converted into heat, producing H calories, then the ratio $W/H = J$ is called the mechanical equivalent of heat or Joule's equivalent. It is a constant quantity. Its numerical value, however, depends on the units in which W and H are expressed. (2) The work is done by electric charges in flowing through the resistance, overcoming the opposition offered by the resistor. The battery supplies the necessary energy. (3) See your text book on Electricity. (4) $R = V/I$. (5) We know $J = W/H$. Due to heat loss the value of H we get is less than the real heat produced. So, H being smaller than the true value, the apparent value of J will be higher than the true value. (6) Mainly by convection and radiation. A part by conduction.

7-11. Experiment 29

To measure a current with a tangent galvanometer

Theory. Let the intensity of the magnetic field at the centre of the vertical coil of a tangent galvanometer be H oersted. Let H_o be the horizontal component of the earth's field at the place.

Then the deflection θ of the magnetic needle at the centre of the coil will be given by

$$H = H_o \tan\theta.$$

At a given place H_o has a fixed value. So $H \propto \tan\theta$, that is, H is proportional to $\tan\theta$. H is also proportional to the current I in the coil. So I is proportional to $\tan\theta$. In such a case, we can write,

$$I = k \tan\theta$$

where k is a quantity whose value at a given place is fixed.

k is called the *reduction factor* of the galvanometer. If k at a place for a given tangent galvanometer is known, the current through the galvanometer can be determined by noting the deflection of the needle.

Apparatus. Tangent galvanometer (TG. Fig. 7.17); a storage cell (B); rheostat (Rh) (5-ohms, 2-ampere); plug key (K_1); ammeter (A) (0→2 amp); a reversing key (K_2); flexible twin cord (TF) a metre or so long; connecting wires; spirit level.

Descritption of the tangent galvanometer. The tangent galvanometer (Fig. 7.16) is a device for measuring electric currents. In it, the electric current flows through a very closely wound, circular coil (C) made of a number of turns of wire of the same radius. The plane of the coil is perpendicular to the platform on which it is mounted. If the platform is horizontal, the plane of the coil is vertical. A small magnetic needle (*ns*) is pivoted at the centre of the coil. It can turn freely in a horzontal plane. An aluminium pointer (P) is attached rigidly to the needle at right angles to it. As the needle turns, the pointer moves over a horizontal circular scale graduated in degrees. The coil can be rotated about a vertical axis in its own plane. There are three levelling screws (L) to make the axis vertical. The plane of the coil must be in the magnetic meridian. The coil has two terminals (T_1, T_2) for connection to the circuit.

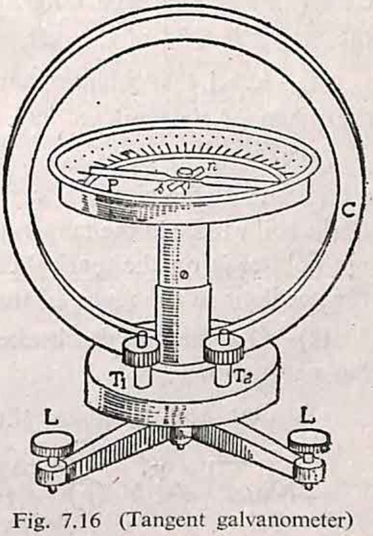


Fig. 7.16 (Tangent galvanometer)

Use of a spirit level. A spirit level is used for testing whether a plane surface is horizontal. (An axis perpendicular to the surface is then vertical.) To make the plane of the coil of a tangent galvanometer vertical, the spirit level is first placed on the platform of the coil parallel to the line joining any two of the screws. The two screws are held between the thumb and the forefinger of each hand, and given opposite turns (one clockwise and the other anticlockwise). Bring the centre of the bubble of the spirit level to the central mark on it by so turning the screws. The proper adjustment will require a little trial. Now place the spirit level perpendicular to its first position. Turn the third screw to centre the bubble. Check if the bubble is still central when the spirit level is placed again in its first position.

With a little practice, levelling will not require more than 2-3 minutes.

[Directions for the experiment.

(1) Build a circuit as shown in Fig. 7.17. Use the flexible twin cord (TF) to keep the tangent galvanometer as far as possible from the magnetic field of the rest of the circuit.

(2) Level the galvanometer with a spirit level. This will make the plane of the coil vertical.

(3) Turn the galvanometer coil to bring its place in the magnetic meridian. If the circular scale has been mounted properly, the plane of the coil will be in the magnetic meridian when one end of the aluminium pointer is on the mark 0°. (As a check you should note whether the needle is in the plane of the coil.)

(4) Get the circuit checked by the teacher and start work with his permission.

(5) Put the plug in the key K_1, and adjust the rheostat Rh so that the deflection is about 30°. Take the readings $(\theta_1^\circ, \theta_2^\circ)$ of both ends of the aluminium pointer.

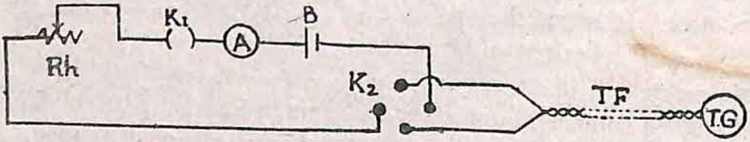


Fig. 7.17 (Circuit diagram for measuring current with a tangent galvanometer)

(6) Use the reversing key K_2 (See Section 7-3iii) to reverse the current in the galvanometer, and take the readings ($\theta_3°$, $\theta_4°$) of the ends of the pointer again. Note the value I of the current as shown by the ammeter.

(7) Adjust Rh to make the deflection 30°, 40°, 45°, 50° and 60° in turn. Reverse the current for each value of the deflection and take the four readings ($\theta_1°$ to $\theta_4°$) for each current. Note also the corresponding current I.

(8) Remove the ammeter from the circuit. Ask the teacher to fix the current which he wants you to measure with the T.G. (Possibly he will alter Rh a little.)

(9) Take the four readings ($\theta_1°$ to $\theta_4°$) of the pointer for this value of the current. (On this occasion you will not have the ammeter in your circuit. This is the unknown current you are measuring.)

(10) Remove the plugs from the keys and disconnect the battery.]

Observations and **Calculations.**

No. of obs.	Current (I) in amp.	Deflection of the pointer in degrees for				Mean deflection $\theta°$	$\tan\theta$	$\frac{I}{\tan\theta}$ =K(amp.)	Mean K (amp.)
		Direct current		reverse Current					
		End I	End II	End I	End II				
1.									
2.									
3.									
etc.									
	Unknown							Unknown $I=K\tan\theta$	

(For values of tangents see p. 149. Express k in decimals. Keep three significant digit. Even the second digit may be uncertain.)

Result.

For the unknown current, the mean value of θ=......° and $\tan\theta$=....
Therefore, the unknown current.

$$I = k \tan\theta = \ldots\text{amp.}$$

Method followed.

(1) The circuit was built as shown in the circuit diagram. The tangent galvanometer was kept away from the magnetic field of the rest of the circuit.

(2) The platform of the galvanometer was made horizontal with the help of a spirit level. This made the rotation axis of the coil vertical.

(3) The coil was turned so that one end of the pointer read 0°. (This brings the plane of the coil in the magnetic meridian.).

(4) Observations were made after the teacher had checked the circuit and given permission for work. The key K_1 was closed and the rheostat was adjusted so that the deflection was 30°. Both ends of the pointer were read ($\theta_1°$, $\theta_2°$).

(5) The current in the galvanometer was reversed by using the reversing key K_2. The readings $\theta_3°$, $\theta_4°$ of the two ends of the pointer were taken. The current I in the ammeter was noted.

(6) The rheostat was adjusted so as to make the deflections 30°, 40°, 45°, 50°, 60°. The pointer readings $\theta_1°$, $\theta_2°$ and $\theta_3°$, $\theta_4°$ on reversal were taken. The current for each set of deflections was noted.

(7) The teacher was then requested to set the current to be measured. The deflections $\theta_1°$, to $\theta_4°$ for this current were noted. In this case there was no ammeter in the circuit.

(8) The plugs from the keys were removed and the battery was disconnected.

Precaution.

There should be no magnetic material or any magnetic field due to a magnet or any other current near the coil. Any of these changes the value of H_o.

Remarks.

(1) If the coil is not in the magnetic meridian, the values of the deflections on current reversal will differ. The same thing happens if the 90°-90° line of the scale is not in the plane of the coil. Draw the attention of the teacher to differences in θ values if they are more than one degree.

(2) It is found theoretically that the reduction factor $k=5rH_o/\pi n$ ampere. Here r=radius of each turn of the coil in centimetres, n is

the total number of turns in the coil and H_o is the horizontal component of the earth's field. At different places H_o is generally different, and so is k.

(3) The error in the result due to an error in the value of θ is the least when $\theta=45°$.

Oral questions. (1) To what use can a tangent galvanometer be put? Describe its action briefly.

(2) What is meant by the 'reduction factor' of a tangent galvanometer? Is its value constant? How does this value depend upon the radius and number of turns of the coil?

(3) What range of currents can you measure with such a galvanometer?

(4) Explain the action of the reversing key.

Answers. (1) Measurement of current. See 'Theory'. (2) "Theory" and para (2) under 'Remarks'. (3) Theoretically, it can measure any current because tan θ varies from O to ∞. But in practice, the values are limited to currents producing deflections of about 30° to 60°. For small or large angles, a small error in reading θ causes a large error in the result. Besides, the wires of the coil must be able to bear the current without appreciable heating. (4) See Section 7-3(iii).

Table of tangents of angles

θ	tan θ	$\theta°$	tan $\theta°$	$\theta°$	tan θ
28	0.532	40	0.839	51	1.23
29	0.554	40.5	0.854	51.5	1.26
30	0.557	41	0.869	52	1.28
30.5	0.589	41.5	0.885	52.5	1.30
31	0.601	42	0.900	53	1.33
31.5	0.613	42.5	0.916	53.5	1.35
32	0.625	43	0.933	54	1.38
32.5	0.637	43.5	0.949	54.5	1.40
33	0.649	44	0.966	55	1.43
33.5	0.662	44.5	0.983	55.5	1.46
34	0.675	45	1.00	56	1.48
34.5	0.687	45.5	1.02	56.5	1.51
35	0.700	46	1.04	57	1.54
36.5	0.713	46.5	1.05	57.5	1.57
36	0.727	47	1.07	58	1.60
35.5	0.740	47.5	1.09	58.5	1.63
37	0.754	48	1.11	59	1.66
37.5	0.767	48.5	1.13	59.5	1.70
38	0.781	49	1.15	60	1.73
38.5	0.795	49.5	1.17	60.5	1.77
39	0.810	50	1.19	61	1.80
39.5	0.824	50.5	1.21	62	1.88

7-12. Principle of the Wheatstone network: The metre bridge and the P.O. box. A Wheatstone network (also called Wheatstone's bridge) consists of four resistances P, Q, R, S arranged as in Fig. 7.18. The battery (E) is connected to a pair of opposite corners, say A and C, of the network. A shunted galvanometer (G) is connected to the other two corners B and D.

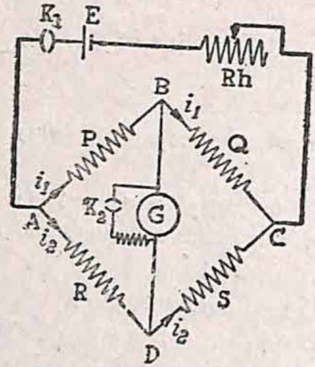


Fig. 7.18 (Circuit showing. action of Whetastone's network)

It can be easily shown that when the ratio of the resistances P/Q is equal to the ratio R/S of the other pair, that is, when

$$\frac{P}{Q}=\frac{R}{S}$$

no current will flow through the galvanometer. (The connections of the battery and the galvanometer can be interchanged. G may be connected to A and C, and E to B and D. In this case also, if $P/Q=R/S$, there will be no current through the galvanometer.)

[When there is no current through the galvanometer, the current along the branch ABC has some fixed value i_1. That along ADC has some other fixed value i_2.]

The action of two electrical measuring devices depends on the above principle of the Wheatstone network. One of them is the **Metre bridge.** The other is called the **Post office Box** (or **P.O. Box** in brief). The Post Office Box was so called because it was originally designed to measure the resistances of telegraph lines in a post office. Both devices can determine an unknown resistance by comparison with a known one.

7-12.1. Metre bridge : Description. The metre bridge has a metre-long wire of uniform cross-section (AC of Fig. 7-19). It is stretched by the side of a metre scale. The ends of the scale and the wire coincide. The ends A and C of the wire are soldered to two L-shaped strips of copper or brass. Between the two L-strips, there is another

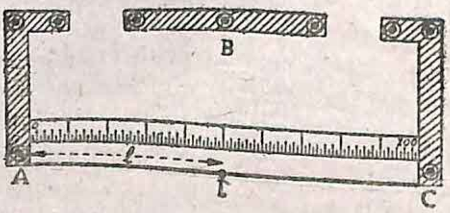


Fig. 7.19 (The metre bridge)

straight strip with gaps on both sides of it. These strips have entirely negligible resistances. Each strip has binding posts at its ends. The straight strip has a third post in its middle. These are used for connection with battery, glavanometer, the known and the unknown resistances. The metrewire, scale and the metal strips are mounted on a wooden board. A contact piece with a knife-edge slides along a groove parallel to the wire. It can establish contact between the galvanometer and any point of the wire. The position of the point of contact can be read off from the scale by noting the position of a mark on the slider.

Action. Suppose the unknown resistance X is in the left gap of the bridge, and a known resistance R in the right gap. By trial, the galvanometer is connected (through the slider) to a point D on the wire such that no current flows through the galvanometer. Let D be at a distance l cm from the end A (left end) of the wire. Since the wire is uniform, the resistances of the portions l and $(100-l)$ cm of it are proportional to these lengths. We can take these two portions to form respectively the P and Q braches of a Wheatstone network. Then for balance (that is, no current in the galvanometer) we shall have

$$\frac{X}{R}=\frac{l}{100-l} \text{ or } X=R.\frac{l}{100-l}.$$

If X is in the right gap and R in the left, the condition for balance will be

$$\frac{R}{X}=\frac{l}{100-l} \text{ or } X= R.\frac{100-l}{l}.$$

7-12.2. Description of the P. O. Box. Its construction is a little complicated. The real form and the diagrammatic representation look very different. Let us try to understand its construction.

Construction. In it, a number of coils of known resistance are arranged to form the arms P, Q and R of a Wheatstone network (See Fig. 7.20). The unknown resistance forms the fourth arm S. The resistances in the P, Q, R arms are connected as in a resistance box (see Section 7-4 iii; Fig. 7.8, *b* and *c*).

In Fig. 7.20, the part AB forms the P arm and BC, the Q arm of the network. These two arms are called the **ratio arms** of the P.O. box. Each of these arms generally contains three resistances in the ratio 10 : 100: 1000. (So the ratio P/Q can be given the values 100, 10, 1, $\frac{1}{10}$, $\frac{1}{100}$.). The third arm R is called the **rheostat arm.** In most instruments it contains resistance coils of values 1 ohm to 4000 ohms. With the help of these coils the resistance in the rheostat arm can be varied from 1 ohm to 11,110 ohms.

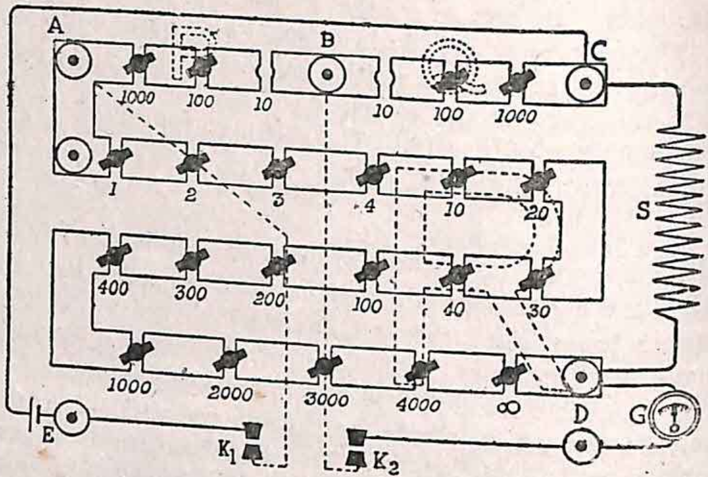


Fig. 7.20 (The P. O. Box)

A P. O. box has two tapping keys K_1 and K_2. (For tapping keys, see section 7-3 ii). One of them is connected to the battery and the other to the galvanometer. One end of K_1 goes to the battery E, and the other end is connected to *A*, the junction of the arms P and R. (This is shown in broken lines in the figure.) One end of the key K_2 goes to the galvanometer G and the other to the junction B of the arms P and Q. (This is also shown in broken lines.)

In many P. O. boxes two terminals are marked B, B for connection with the battery. Two other terminals are marked G, G for connection with the galvanometer. A third pair of terminals may be marked L, L or X, X for connecting the unknown resistance. Such markings help the beginner to make the connections correctly. Otherwise he has to identify all the connecting posts. (If the terminals are not marked, try to identify them. If you fail, seek the teacher's help.)

Diagrammatic representation or Symbol. To represent a P.O. box on a circuit diagram, we shall use the symbol as shown in Fig. 7.21. The letters P, Q, R and S have the same meanings as in Fig. 7.20.

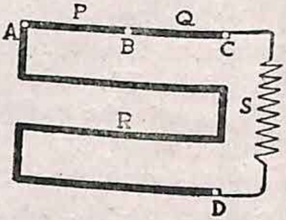


Fig. 7.21 (Diagrammatic representation of a P.O. Box)

7-13. Experiment 30

To measure an unknown resistance with a metre bridge

Theory. The metre bridge acts on the principle of the Wheatstone bridge. For no current through the galvanometer we can write,

$$\frac{\text{Resistance in the left gap}}{\text{Resistance in the right gap}} = \frac{\text{distance of the null point from the left end}}{\text{distance of the null point from the right end}}.$$

Let R be the resistance in the left gap and X, that in the right gap of a metre bridge. If the null point on the wire is l cm from the left end of the wire then, we have

$$\frac{R}{X} = \frac{l}{100-l}.$$

If R is known, X may be determined by finding l.

Apparatus. Metre bridge with slider; Unknown resistance X (about 5 ohms will be suitable); a known resistance R (a resistance box of range 1→10 ohms will be suitable); a Leclanche' or a Daniell cell; plug Key; Sensitive galvanometer; connecting wires; rheostat; high resistance box.

(The metre bridge has been described in Sec. 7-12.1)

[Directions for experiment.

(1) Build a circuit as in Fig. 7.22. Put 5 ohms in the resistance box R, which is in the left gap. The connecting wires for R and X should be short and thick. Put 100 ohms resistance from resistance box R′. The current through the galvanometre will be low. Also

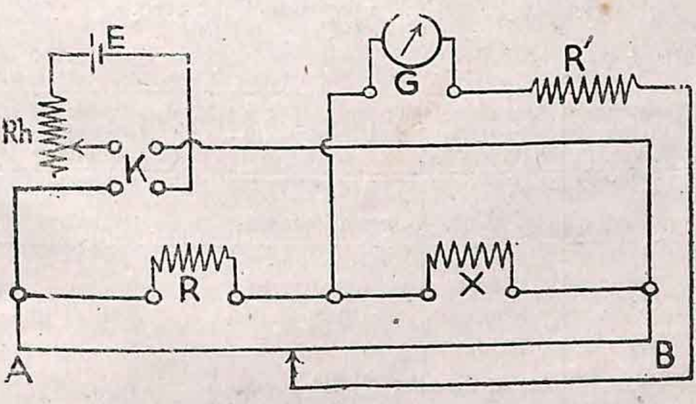


Fig. 7.22 (Diagram showing use of metre bridge)

make Rh high. Get the circuit checked by the teacher. After he has approved, close the key K by inserting the plugs in the diagonally opposite sockets.

(2) Touch the slider to some point near the middle of the wire and note the deflection of the galvanometer needle. Adjust the resistance in the box R to reduce the deflection as far as possible. Then bring the deflection to zero by slowly moving the slider.

(3) Reduce R′ to zero and make Rh as low as possible. The galvanometer acquires its full sensitivity and may show some deflection. Reduce this to zero by moving the slider slowly and find the position of the null point. Note this length.

(4) Reverse the current by interchanging the key to the opposite diagonal and note the null point again.

(5) By increasing and decreasing the resistance in the resistance box R, find the null points at least twice. Note the null points twice for each resistance, one for the direct current and another for reverse current. The null points should in all cases preferably lie within the approximate range 45 cm to 55 cm. The bridge is most sensitive at the middle.

(6) Interchange R and X (that is, put R in the right gap and X in the left gap). Repeat the operation (2), (3) and (4) and note the null points for direct and reverse currents putting the same resistance as before.

(7) Open the plug Key K. Disconnect the cell].

Observations

No. of obs.	Resistance in the left gap in ohm.	Resistance in the right gap in ohm.	Position of the null point l cm for		Mean l in cm.	value of the unknown resistance X in ohm.	Mean X in ohm.
			direct current	reverse current			
1. (a)	R_1	X					
(b)	X	R_1					
2. (a)	R_2	X					
(b)	X	R_2					
⋮							
etc.							

Calculation. from the formula, $\frac{\text{resistance in the left gap}}{\text{resistance in the right gap}}=\frac{l}{100-l}$

we get for observation (a)'s (1) $\frac{R}{X}=\frac{l}{100-l}$ ... etc.

and for observation (b)'s (1) $\frac{X}{R}=\frac{l}{100-l}$ ... etc.

Hence the mean resistance=... ohm.

Result. The given value of the unknown resistance is...ohm.

Method followed.

(1) A circuit was built as shown in the circuit diagram (Fig. 7.22). A resistance of 5 ohms was put in the known resistance box. The other plugs of the box were checked to see if they were tight. A 100 ohms resistance was put in R′ and Rh made large.

(2) The plugs were inserted in the opposite diagonals and the slider was touched to the middle of the wire and the deflection of the galvanometer was noted. The resistance in the known resistance box was changed to make the deflection as small as possible. The slider was slowly moved to reduce the deflection to zero.

(3) The galvanometer made sensitive by making R′ to zero and Rh least. The deflection increased a little. The slider was moved very slowly to reduce this to zero. The position of the null point was noted. The null point was again noted by reversing the current.

(4) By increasing and decreasing the resistances in the box the null points were again noted by the above procedure.

(5) The known and unknown resistances were interchanged and the null point were noted for direct and reverse current for each resistance.

(6) The circuit was dismantled.

(7) The value of the unknown resistance was calculated by the formula and the mean taken.

Precautions.

(1) Plugs left in the resistance box should sit tight.

(2) R and X should be connected to the bridge by short, thick wires.

(3) The null points should lie within the range 45 cm to 55 cm. (The error increases if it goes too far to one side.)

(4) The slider should not be in contact with the wire except during adjustment or taking a reading.

Oral questions. (1) What is a Wheatstone network (or Wheatstone bridge)?

(2) Bring out the similarity between a Wheatstone network and the metre bridge.

(3) How does a metre bridge measure an unknown resistance?

(4) Why are you taking readings with the resistance in the gaps interchanged?

(5) Does the position of the null point depend on the current in the circuit?

(6) Why do you use short, thick wires for connection with the resistances?

Answers. (1) See Section 7-12. (2) See the portion marked 'Action' under Section 7-12.1. (3) See 'Theory' of this experiment. (4) To reduce the error in the experiment. (5) It does not. (6) R, X actually include that resistances of the connecting wires. Hence these should be kept as small as possible.

7-14. Experiment 31

To measure an unknown resistance with a P.O. Box.

Theory. In the figure (Fig. 7.23), P, Q are the ratio arms and R the rheostat arm of a P.O. box. The resistances are R_1 in P, R_2 in Q, R_3 in R. If the unknown resistance S has a value X then, according to the principle of the Wheatstone bridge, we shall have

$$\frac{R_1}{R_2}=\frac{R_3}{X}$$

for no current through the galvanometer. When this relation is satisfied

$$X=R_3.(R_2/R_1)$$

When the ratio R_2/R_1 is known and the bridge is balanced (that is, there is no current through the galvanometer), X is found by multiplying R_3 by this ratio.

Apparatus. P. O. box; unknown resistance (a value around 10 ohms will be suitable); Leclanche′ or Daniell cell; galvanometer with shunt; connecting wires.

[The P. O. box has been described in Section 7-12.2.]

Directions for the experiment.

(1) Build a circuit as in Fig. 7.23. Put resistances of 10 ohms each in the arms P, Q and R. Take care to see that all other plugs are tight, and no connection is loose. Note whether your P.O. box has terminals marked B, B; G, G; and X, X. If so, connect the battery terminals to B, B; the galvanometer terminals to G, G; and the terminals

of the unknown resistance to X, X. Otherwise, you have to trace where to connect which by identifying the arms P, Q, R, S of Fig. 7.20. If you fail to do so, seek your teacher's help.

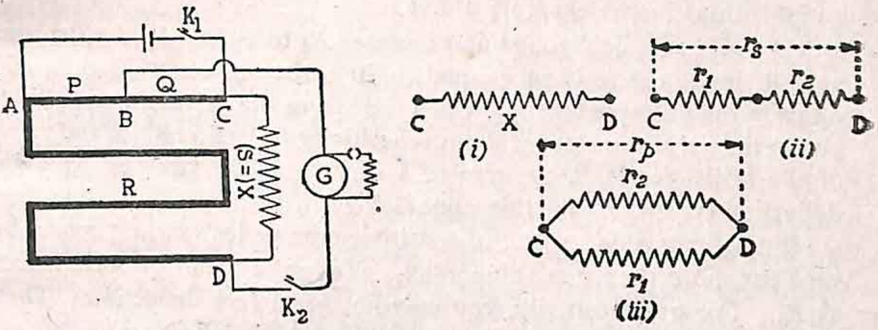


Fig. 7.23 (Circuit diagram for using P.O. box, (*i*) is for resistance determination, (*ii*) for verifying law of series resistances, and (*iii*) for parallel resistances.

(2) Get your circuit checked by the teacher. If he approves, start work.

(3) Press the battery key K_1 first and then the galvanometer key K_2. Remember, both are 'tapping keys' (see Section 7-14.2 and 7-3ii). Note the direction of deflection of the galvanometer needle. Release the galvanometer key first and then the battery key. (Both these circuits will then be broken.).

(4) Reduce R_3 (the resistance in the rheostat arm) to 1 ohm. Press K_1 and then K_2. Note the direction of deflection of the needle. Perhaps it will be opposite to that on the first occasion. (We shall assume this to be the case and proceed accordingly. If, however, deflections on both occasions are in the same direction, try successively values of 20 ohms, 30 ohms, 40 ohms etc. in the rheostat arm until you have found that a deflection in the opposite direction occurs.).

(5) The value of the unknown resistance X lies somewhere within the range of resistances in which opposite deflection occur. Reduce the upper limit of this range by 1 ohm at a time, and note the direction of deflection. In this way reduce the range to the smallest value. Suppose the limiting values of the range are $(n+1)$ and n ohms. X lies between n and $n+1$ ohms.

[For example, if the direction of deflection changes between 5 ohms and 4 ohms, $n=4$ ohms.]

(6) Now change R_1, the resistance in the arm P, from 10 to 100. Keep R_2 at its old value (10). Increase R_3 to $10(n+1)$.

[In the example above, this will be 50 ohms.] Again reduce this value by steps of 1 ohm until the direction of deflection reverses. Suppose this occurs between $10n+5$ and $10n+4$ [that is between 45 and 44 ohms in the example above.]

(7) Keep R_2 unchanged and increase R_1 to 1000. In the rheostat arm R, make the resistance equal to $10\times(10n+5)$ ohms [that is, 450 ohms in the example taken]. Open the key of the galvanometer shunt, giving the galvanometer maximum sensitivity. Again reduce the value of the resistance in R by steps of 1 ohm each till you find that the deflection is zero. Then this value is R_3.

(Sometimes, due to lack of sensitivity the deflection appears to be zero for more than one value of R_3. Take the mean of such values as R_3. For oversensitivity, you may not get a zero deflection. Then take R_3 as that value which gives you the smallest deflection.).

(8) The values you have got for no current in the galvanometer are: $R_1=1000$ in arm P, $R_2=10$ in arm Q and R_3 in arm R. So, according to theory, the unknown resistance $X=R_3.(10/1000)=R_3/100$].

Observations.

(These may be arranged in the following tabular form)

	Resistances in different arms			Direction of deflection	Conclusion
	R_1 in P	R_2 in Q	R_3 in R		
	10	10	10	Right	X lies between 5 and 4 Ohm
	10	10	1	Left	
	10	10	9	Right	
	..	..	..	..	
	10	10	5	Right	
	10	10	4	Left	
X Unknown	100	10	50	Right	X lies between 4·5 and 4·4 Ohm
	..	..	..	..	
	100	10	45	Right	
	100	10	44	Left	
	1000	10	450	Right	
	1000	10	446	Right	
	1000	10	445	No deflection	$X=4·44$ Ohm
	1000	10	444	No deflection	
	1000	10	443	No deflection	
	1000	10	442	Left	

Calculations and Result.

When the bridge was balanced it was found that

$R_1=1000$, $R_2=10$, $R_3=$...ohms (444 in the example). Hence the unknown resistance

$$X=\frac{R_2}{R_1}.\ R_3=\frac{10}{1000}\times\ldots \quad =\ldots \text{ ohms.}$$

[In the example taken it will be 4·44 ohms.]

Method followed.

(1) A circuit as in the circuit diagram (Fig. 7.23, left) was built. 10-ohm plugs were removed from each of the arms P, Q, R. The circuit was checked by the teacher. With his approval I started work.

(2) I noted the direction of deflection of the galvanometer, pressing the battery key first and then the galvanometer key. The same was noted after putting 1 ohm in the rheostat arm instead of 10. The galvanometer showed a deflection in the opposite direction to the first.

(3) R_3 was reduced by steps of 1 ohm at a time (from 10 ohms). The direction of deflection was noted each time. This was carried on until on changing R_3 from...ohms $[n+1]$ to ...ohms $[n]$ the deflection reversed direction.

(4) R_1 in the P arm was given the value 100. R_3 was given the value ...ohms $[10(n+1)]$. Again R_3 was reduced by 1 ohm at a time until the deflection reversed. This occurred between ...ohms and ...ohms.

(5) R_1 was raised to the value 1000. R_3 was also increased ten times. The key of the galvanometer shunt was opened. By changing R_3 by 1 ohm at a time, the position of balance (that is, no deflection in the galvanometer) was found at ...ohms. From this X was calculated.

(6) The circuit was dismantled.

Precautions.

(1) All the plugs that remain in place in the P.O. box must be tight.

(2) The connecting wires must be tight. This is checked by lightly pulling each wire at its junction.

(3) In all cases the battery key is pressed first and then the galvanometer key.

Oral questions. (1) What is a P.O. box? Why is it so named? (2) What is its theory of action? (3) Does the condition of no deflection depend on the current in the circuit? (4) Will the condition of balance change if the battery and the galvanometer are interchanged? (5) Why do you think it necessary to press the battery key first and then the galvanometer key?

Answers. (1) See Sections 7-12 and 7-12.2. (2) See Theory'. (3) It does not. (4) It will not. (5) When the battery key is pressed with the galvanometer in the circuit, the rise in current in the circuit may send a momentary current through the galvanometer due to self-induction, giving the needle a kick.

7-15. Experiment 32

To verify the laws of series and parallel resistance with a P.O. Box

Theory. (A). If two resistances r_1 and r_2 are connected in series their equivalent resistance r_s is given by

$$r_s = r_1 + r_2.$$

(B) If two resistances r_1 and r_2 are connected in parallel their equivalent resistance r_p is given by

$$\frac{1}{r_p} = \frac{1}{r_1} + \frac{1}{r_2}.$$

(C) According to the principle of wheatstone bridge, for no current through the galvanometer we have $\frac{P}{Q} = \frac{R}{X}$. This principle may be used for measuring r_s and r_p. Determining or knowing the values of r_1 and r_2, the laws can be verified.

(The laws apply to more than two resistances also.)

Apparatus. P.O. box; two resistances r_1 and r_2 whose values will be supplied at the end of the experiment (2 and 5 ohms or 5 and 10 ohms are suitable); Leclanche' or Daniell cell; galvanometer with shunt; connecting wires.

[Directions for the experiment.

(1) Build a circuit as in Fig. 7.23. But in place of the unknown resistance X in that figure, first substitute the series combination of r_1 and r_2 (as shown at (*ii*) in the figure), and then the parallel combination of r_1 and r_2 (as shown at (*iii*) in the figure). Determine r_s and r_p. All other directions are as in Experiment 31 (sec. 7-14). If r_1 and r_2 are not known then determine the values of r_1 and r_2 first.]

Observations. If r_1 and r_2 are unknown then make four tables for r_1, r_2, r_s and r_p as in Experiment 31. But if r_1 and r_2 are known, then make only two tables for r_s and r_p.

Calculation and Conclusion.

r_1 (ohm)	r_2 (ohm)	Combination of r_1 and r_2 in	Combine resistance of r_1 and r_2 according to		Conclusion
			formula	experiment	
		Series	....	....	Within the limits of experimental error the laws of series resistances and parallel resistances are verified.
		Parallel	....	....	

Method followed. (1) to (5) as in experiment 31; but write r_1 for x.

(6) By same procedure r_2, r_s and r_p were found.

(7) The circuit was dismantled.

Precautions. As in experiment 31.

Oral questions. (1) What is series combination of resistance?
(2) What is parallel combination of resistance?
(3) Is these laws applicable to any number of resistances?

Answers. (1) A combination of resistances in which the same current flows through all of them is a series combination. The effective resistance r_s of a number of resistances in series is higher than the highest of the connected resistances. (2) When one end of a number of resistors is connected to one point and the other ends to anoter point, the resistors are said to be connected in parallel. The effective resistance r_p of a number of resistances in parallel is lower than the lowest of the connected resistances. If the resistances are different, the current flowing through each is different. The total current is the sum of all these currents. (3) The laws of series resistances and parallel resistances apply to any number of resistances.

West Bengal Council of Higher Secondary Education

Physics Practical Examination-1985

(General Stream Course)

Time : 3 hours

Full marks : 40

Answer two questions taking one from each of Group A and Group B. The experiment of Group A is to be completed within 1 hour and the question carries 12 marks; the experiment of Group B is to be completed within 2 hrs. and the question carries 18 marks. Laboratory Notebook—6 marks; Viva voce—4 marks.

Group A

1. Determine the volume of the given solid of irregular shape, heavier than water and insoluble in water by a hydrostatic balance.
2. Determine the specific gravity of the given solid insoluble in water and lighter than water by a hydrostatic balance.
3. Determine the specific gravity of the given solid insoluble in water and heavier than water by a hydrostatic balance.
4. Determine the specific gravity of the given liquid by a specific gravity bottle.
5. Determine the velocity of sound in moist air with the help of resonance air column. (Neglect correction due to temperature.)
6. Verify the laws of reflection of light by the pin method using a plane mirror. (The experiment is to be done with at least three angles of incidence.)
7. Verify the laws of refraction of light by the pin method using a rectangular glass slab. (The experiment is to be done with at least three angles of incidence.)

Group B.

1. Determine the specific gravity of the given granular solid insoluble in water by a specific gravity bottle.
2. For a simple pendulum show that the squares of the time-periods are proportional to the effective lengths ($T^2 \propto l$). Draw a graph with the readings of T^2 against l. From the readings or from the graph determine the value of 'g'. (At least three effective lengths differing by not less than 5 cm are to be taken. The diameter of the bob will be supplied.)
3. Determine the Young's modulus of the material of the given wire by the Vernier method or Searle's method and verify Hooke's law by drawing load-elongation curve.

(Readings are to be taken for at least five different loads and for load increasing and decreasing. Young's modulus may be calculated with or without the help of the graph.) [Diameter of the wire will be supplied.]

4. Verify Boyle's law of gas using different pressures—atmospheric pressure, two pressures below the atmospheric pressure and two pressures above the atmospheric pressure.

Draw $p-v$ or $p-l$ graph. (Atmospheric pressure will be supplied.)

5. Determine the value of the mechanical equiavalent of heat by electrical method. (Neglect radiation correction. Specific heats of oil and the material of the calorimeter will be provided.)

6. Determine, by the method of mixtures, the latent heat of fusion of ice. Neglect radiation correction. (Specific heat of the material of the calorimeter will be supplied.)

7. Determine the frequency of the given tuning fork by a sonometer. (Use at least three different tensions.) (Mass per unit length of the string will be supplied.)

8. Determine the focal length of the given convex lens by the $u-v$ method. Draw $u-v$ graph. (Take at least five object distances, and the successive object distances differing by at least 2 cm.)

9. Draw the lines of force due to a bar magnet with its N-pole pointing north and indicate the neutral points on the map.

10. Draw the lines of force due to a bar magnet with its N-pole pointing south and indicate the neutral points on the map.

11. Verify Ohm's law using an ammeter and a voltmeter and determine the value of the given unknown resistance. Draw $V-I$ graph. (At least five different sets of readings are to be taken to verify the law.)

12. Determine the values of the two given unknown resistances separately and when connected in parallel with the help of a P.O. Box and verify the law of parallel resistances.

13. Determine the resistance of the given wire using a Metre Bridge. (Use at least three known resistances for determining the resistance of the wire and take readings by interchanging the positions of the wire and the known resistances.) [Ignore the end corrections.]

14. Determine the reduction factor of the given tangent galvanometer with the help of a milliammeter supplied. Find the value of the two currents corresponding to the deflections 30° and 60° of the galvanometer.

LOGARITHMS

	0	1	2	3	4	5	6	7	8	9	Mean Differences								
											1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7

Some useful logarithms

$\log \pi = 0.4971$

$\log 76 = 1.8808$

$\log 273 = 2.4362$

$\log 980 = 2.9912$

$\log 13.6 = 1.1335$

$\log 4.2 = 0.6232$

LOGARITHMS

	0	1	2	3	4	5	6	7	8	9	Mean Differences								
											1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7038	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9350	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

Some useful constants

$\pi = 3.1416 = 3.142$

$\pi^2 = 9.8696 = 9.870$

$e = 2.71828\ldots\ldots = 2.718$

$\log_e 10 = 2.30258\ldots = 2.303$

$$e = 1 + \frac{1}{1\,!} + \frac{1}{2\,!} + \frac{1}{3\,!} + \frac{1}{4\,!} + \cdots\cdots\cdots \text{ to } \infty$$

ANTILOGARITHMS

	0	1	2	3	4	5	6	7	8	9	Mean Differences								
											1	2	3	4	5	6	7	8	9
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6

Conversion table

	Reciprocal		Reciprocal
1 inch = 2.54 cm	0.3937	1 lb = 453.6 gm	0.0022
1 yard = 0.9144 m	1.0936	= 0.4536 Kgm	2.2046
1 cu. ft. = 28.32 litres	0.03531	1 gallon = 4.546 litres	0.2200

ANTILOGARITHMS

	0	1	2	3	4	5	6	7	8	9	Mean Differences								
											1	2	3	4	5	6	7	8	9
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
·53	3388	3306	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
·66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

Conversion table (Contd.)

	Reciprocal
1 atmos. $=1.013\times10^6$ dynes/sq. cm.	9.873×10^{-7}
1 gm/c.c. $=62.43$ lb/cu. ft.	0.01602
1 radian $=57.3$ degrees	0.01745
1 calorie $=4.185$ joules	0.2389

$\log_e x=\log_e 10\times\log_{10}x=2.303\times\log_{10}x$

Dr. D. P. Raychowdhuri needs no introduction to the scientific community. A lifetime spent in teaching of Science has enabled him to keenly appreciate the problems faced by students in mastering the subject. This lucid book is the fruit of Dr. Raychowdhuri's labours to solve there problems. Dr. Raychowdhuri has been ably assisted in this task by professor D. K. Ray who has been 17 years experience of teaching physics.

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